Sewage Research

Rejuvenated Sludge

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TRANSLATED BY G. P. EDWARDS

Under the above title, the Editor of SEWAGE WORKS JOURNAL humourously hinted in the April, 1930, number that until recently sewage sludge has been treated very badly inside the digestion tank. The sludge has been neglected and allowed to stew in its own acid juice. It was pointed out that in the future more care must be taken to keep sludge warm in a well-insulated tank and to add a correctly balanced food with the proper pH value, maintained by occasional addition of sodium carbonate or lime. The rejuvenated sludge compensates for this care by yielding an odorless gas of great heat value. It may be of interest to know that for four or five years we have been operating digestion tanks of the Emschergenossenschaft in Essen according to these suggestions with good results. We have given a still more literal interpretation to the idea of rejuvenated sludge than the editor has indicated.

The improvement in the digestion of sludge by maintaining the proper temperature in the digestion tank and by regulating the pH value is so well understood by sewage workers that I will not discuss it further. However, even if these conditions are fulfilled in a quiescent digestion tank, the fresh sludge forms in layers over the old sludge and digestion practically stops at the bottom of the tank. In an article published in *Technisches Gemeindeblatt*,[1] 1927, I pointed out that the sludge in the lowest layers of a quiescent digestion tank contains little water and the organisms which cause the sludge to digest become poisoned by their own secretions. I proposed to pump the old sludge once daily from the bottom of the tank to the surface. The harmful toxins are washed from the heavy sludge as it sinks through the sludge liquor and the old sludge is constantly inoculated by the liquor, which is very rich in bacteria. This frequent inoculation of the old sludge with the active bacteria accomplishes a real rejuvenation of the old sludge. I will return later to the technical details of vertical mixing. We have carried out such a vertical mixing in a large number of digestion tanks of 900 to 1500 cu. meters capacity. Operating results of these tanks have shown that it is not sufficient to inoculate the old sludge frequently

with new, active bacteria but that care must also be taken to furnish the bacteria with the most favorable nutritive conditions. This condition is not fulfilled unless a sufficient quantity of material easy for the bacteria to digest is constantly mixed with the old sludge, so that the necessary balance is assured in the nutrition of the bacteria. In the old sludge all easily digestible materials are exhausted. The substances which remain will not support the bacteria which digest the sludge and digestion practically stops. The missing materials cannot be replaced by the addition of lime or soda as the editor suggested when he recommended a well balanced diet for the bacteria.

In 1928[2] I referred to an investigation made by Bach and Sierp[3] in the laboratory of the Emschergenossenschaft which will be briefly described below and which has set us on the right path. In 1924 a well digested sludge from the bottom of an Imhoff tank yielded no gas even when the toxins were washed out and when it was kept at a favorable temperature in the laboratory. It was considered completely digested. This sludge was mixed with easily digestible materials such as raw meat, cooked eggs and grape sugar solutions and immediately an active digestion set in. An examination of the gas formed and of the sludge consumed brought out the surprising fact that, assuming that all of the material newly introduced into the sludge was gasified, the digested sludge originally present decreased from 5 to 12 per cent. In the presence of these easily digestible materials constituents of the old sludge which previously had not been attacked by the bacteria were further gasified. Since easily digestible substances are contained in every fresh sludge the frequent and intimate mixing of old sludge with fresh or young sludge must have the same result as the mixing of the easily digestible substances with the digested sludge in the Bach and Sierp investigation. The easily digestible substances in the fresh sludge act as a source of energy for the bacteria living in the old sludge. In this way the bacteria so stimulated attack the substances in the old sludge which they did not previously digest.

In a practical application of the experiment the entire contents of the digestion tank were mixed daily with the fresh sludge. Thus the old sludge by mixture with even a small amount of fresh sludge became rejuvenated in a literal sense. We have kept our digestion tank in continuous operation for several years and have determined that the vertical mixing of the fresh sludge with all of the old sludge increases the gas yield about 100 per cent. We do not agree with the common practice of mixing the daily addition of fresh sludge only once with about the same quantity of well digested sludge in order to prevent acid digestion. One may consider that the rapid digestion of the easily attacked ingredients of the sludge is like the rapid combustion of straw, without any action on the old sludge. Instead of mixing the fresh solids only once with ripe sludge it seems more advisable to us to

mix the largest possible amount of old digested sludge with the fresh solids, added daily, in order to stimulate the slow digestion in the old sludge.

Several theories have been mentioned in articles on sludge digestion in the April, 1930, number of THIS JOURNAL against the practicability of this daily sludge mixing. In the first place all preliminary mechanical difficulties were overcome. We use a vertical mixing pump (Figure 1) which is driven by an electric motor placed outside of the digestion tank (Figure 2) and which can be removed for adjustment and repairs. The pipe through which the sludge rises extends down to just above the bottom of the tank. A concrete casing protects it from corrosion by the sludge. The blades of the pump are placed in the pipe about 0.75 meter below the sludge surface. Flat bottom tanks which require the use of scrapers should be avoided since we have found that all delicate iron parts are attacked by the sludge. We prefer tanks with sloping bottoms which allow the sludge to settle to a gutter by its own weight. The cost of a sludge tank with a bottom sloping less than 45° should not be greater than that of a flat bottom tank of equal size, so that not only can the cost of the scrapers be saved but the repair and maintenance of movable parts in the bottom sludge is eliminated.

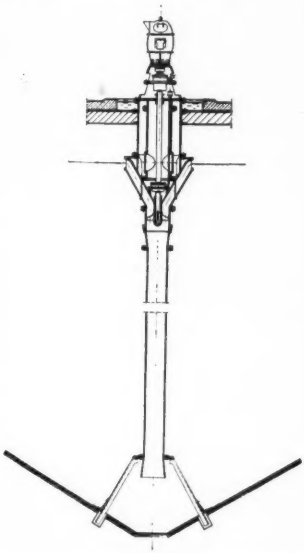

FIG. 1.—Details of Screw Pump for Artificial Sludge Rotation.

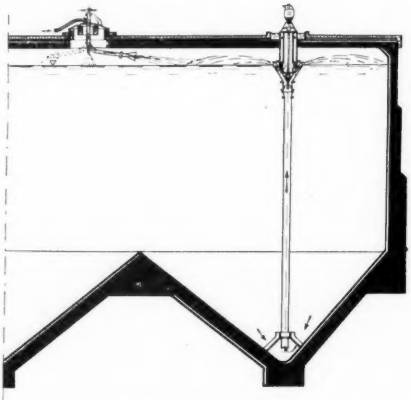

FIG. 2.—Installation of Screw Pump in a Sludge Digestion Tank.

The pump is operated in such a way that the contents of the digestion tank are rotated once each day. This generally requires from one to two hours of pumping. The objections that the sludge does not settle and that it contains more water after such mixing are unfounded.

Each sludge particle is in rapid motion only a few seconds each day while it passes up through the sludge pipe. The sludge is sprinkled over the surface and sinks slowly through the sludge liquor to the bottom where it remains quietly until the next day. The sludge particles do not absorb more water as they slowly sink through the sludge liquor. It would, of course, be wrong to operate the rotation apparatus continuously as the sludge would not come to rest. We have never operated in this way. The direction in which the screw of the pump turns is changed on alternate days so that the scum which is broken up and moistened during normal operation is drawn from the surface and forced below into the sludge. In this way, all difficulties in operation due to scum are eliminated. The gas dome must be placed 30–50

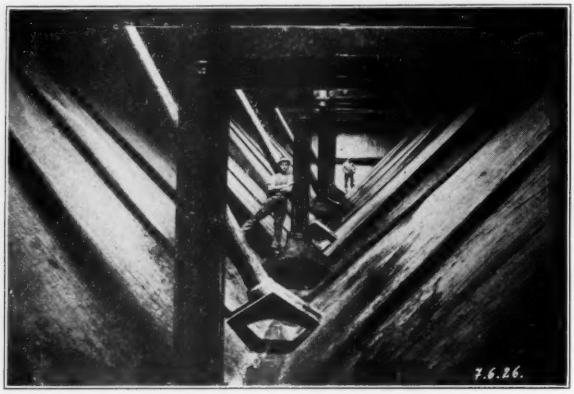

FIG. 3.—Separate Sludge Digestion Tank at Essen-Nord.

cm. above the sludge level for this type of scum control. Contrary to common opinion, there is no danger of explosion in this free space.[4] By mixing the entire contents of the tank it is possible to maintain the desired temperature throughout the entire sludge tank, when artificially heated. Dr. Sierp[5] has correctly pointed out the fact that sludge permeated with gas is a poor conductor of heat. However, with stationary heating apparatus, heat may be distributed equally over the whole tank. Dr. Sierp's objection to such distribution of artificial heat is surprising and his proposal to insulate the outer tank wall with layers of cooled sludge must be challenged from the viewpoint of a construction engineer. This method of insulation is not economical since the digestions slows up in the cool part of the tank making necessary a tank larger than would be required with proper insulation.

The most valid theoretical objection to daily vertical sludge mixing is that small amounts of undigested sludge may be drawn off on to the drying beds

with the ripe sludge, causing difficulties with odors and flies. Five years operation of digestion tanks in Essen-Nord (Figure 3), Oberhausen, Gelsenkirchen and outside the Emschergenossenschaft have shown these objections to be contrary to experience. The fresh sludge added daily is intimately mixed with 30–50 parts of digested sludge, permitting the destruction of the easily digestible substances in the fresh sludge in a few days. During five years continuous operation, we have never had any difficulty to speak of in the drying of our ripe sludge, which undoubtedly contained small amounts of fresh sludge. In spite of the content of fresh sludge, this ripe sludge contained less organic matter than the ripe sludge from a tank digesting the sludge in layers, a proof that mixing the sludge is beneficial. Buswell[6] has shown that fresh sludge digests rapidly when the digestion is carried on in two stages. The first stage, which is complete in several days, yields a large volume of gas which contains most of the hydrogen sulphide. These observations agree with those of Hatfield and others who have reported that 50 per cent of the total gas is produced in the first 24 hours. Buswell has shown that 90 per cent of the total gas is produced in the first stage during the first few days and that only 10 per cent of the gas is produced during the longer second stage. This seems to be clear proof that the total separation of old sludge from fresh sludge in two stages is not to be recommended. During the second stage, the digestion proceeds so slowly that increasing the speed of digestion by stimulation of the bacteria seems very desirable. This is especially desirable when digestion is carried on in artificially heated tanks since the cost of heating the sludge during this longer period in the larger tank required is considerably greater than with rapid digestion of all the sludge in one stage in a smaller tank. In our digestion process we no longer recognize an older stage of sludge in the tanks but after a sufficiently long digestion period we do have only ripe sludge which may be completely drawn off on drying beds without any difficulties. The fresh sludge by its distribution throughout the entire tank becomes ripe in one day. It is important that the ripe sludge to which the fresh solids are added should be built up slowly and that a sufficient quantity should be present. Under German conditions this amounts to about 30 liters per capita digestion tank capacity. No lime is required to maintain the pH at 7.3 with this capacity. If sludge digestion in two stages is contemplated, then the tank for the second stage should be of such size that it will hold one drawing of sludge onto the beds, or in other words it should be about $^1/_{30}$ the capacity of the first stage. The small amount of fresh sludge still feared by many to be present in the sludge as drawn is surely changed to ripe sludge in the second stage during the week between sludge drawings.

In my opinion, the numerous advantages of frequent mixing of fresh sludge with ripe sludge should be reason enough for the operators of larger treatment plants to test the method in a practical way, in spite of all the

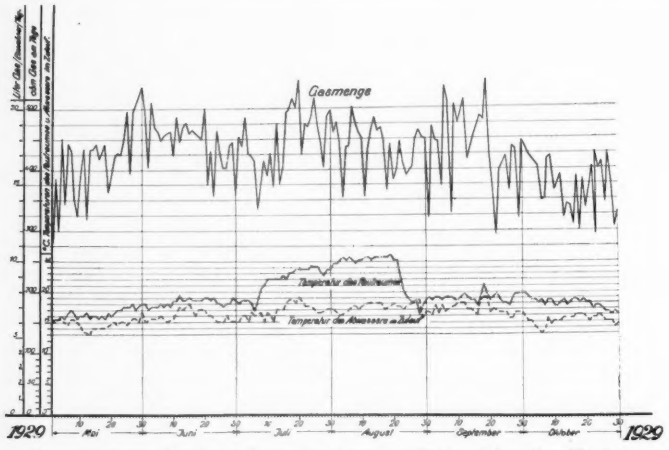

FIG. 4.—Operating Data from the Separate Sludge Digestion Tank at Essen-Frohnhausen.

theoretical objections, which are based mostly on laboratory investigations. I believe that an experimental tank for a practical test should be at least 300–500 cubic meters in capacity. Our scheme of operation is somewhat similar to that of the Sheffield type of activated sludge treatment, in which

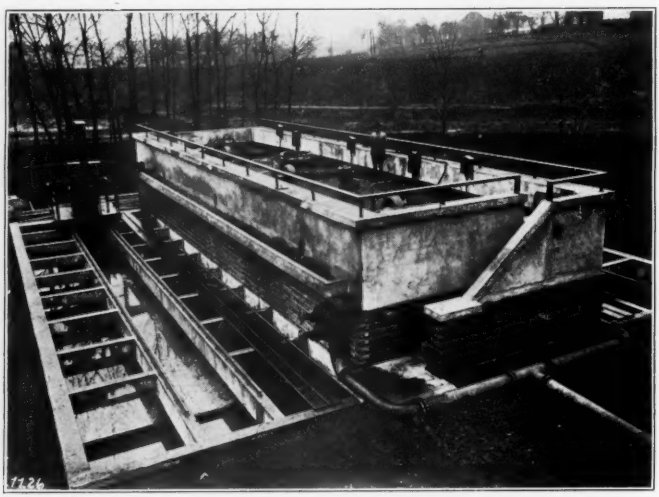

FIG. 5.—Settling Tanks with Separate Sludge Digestion at Essen-Frohnhausen.

the liquid plus sludge is driven by paddles through an endless channel. The total period of agitation is 15 to 18 hours. About 15 to 20 minutes are required for one complete circulation. Sewage is constantly added to the sludge-water mixture in the circulation channel and a corresponding quantity of purified liquor is constantly removed on the effluent side. As long as the required degree of purification is obtained in the effluent, the fact that there is a variation in the time spent in purification, with a minimum of only 15 minutes, is of little importance.

The operating data from our treatment plants prove that a well-digested sludge can be obtained by our process. Figure 4 shows the daily amount of gas obtained during the half-year, May to October, 1929, from the 900 cubic meter digestion tank at Frohnhausen (Figure 5), which treats the sewage from 25,000 inhabitants of Essen. No industrial wastes are included. The tank has a capacity of 36 liters per capita. The temperature chart shows that the temperature of the sludge in the digestion tank was raised 2–3° C. artificially. The average gas yield during this time amounted to about 17–18 liters per capita per day. It is interesting to note that the temporary increase in temperature to 25° C. during July and August hardly increased the amount of gas produced, an indication that artificial sludge rotation with a digestion space of 36 liters per capita is enough to develop the maximum amount of gas at 18° C. We have obtained similar results in other tanks provided with artificial circulation. About one liter of sludge is received per capita per day. This sludge with 95 per cent water contains about 50 grams of dry solids of which 30–35 grams are organic matter.

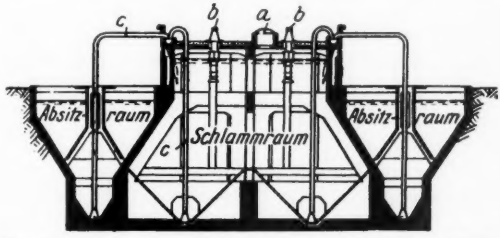

FIG. 6.—Cross-section of the Oberhausen Treatment Plant.

a. Gas domes

b. Screw pump for sludge rotation

c. Pump for introduction of fresh solids or withdrawal of ripe sludge.

Figure 6 shows a cross section of the Oberhausen plant, which is similar in construction to the Frohnhausen plant. The digestion tank, built above the ground surface, is connected to the settling compartment along its entire length by a thin reinforced-concrete wall which permits the transfer of heat from the warm sewage in the settling tank to the sludge in the digestion compartment, as in an Imhoff tank. In large treatment works, the digestion chamber would be completely separated from the settling tank and the temperature of 25° C. maintained by artificial heat. Under such condi-

tions 30 liters per capita digestion space with sludge circulation and artificial heating to 25° C. would be sufficient and 18–20 liters of gas per capita per day could be expected. This means a real saving in capital investment due to the smaller digestion tank, besides the saving in heat in the artificial heating of the digestion tank. Likewise there is nearly double the yield in digestion gas, which is sufficient in all cases to furnish power for the operation of an activated sludge plant.

Conclusions

1. Sludge may be rejuvenated by daily mixing of the fresh solids with all the old sludge in a digestion tank.

2. The fresh solids are so well distributed in the digested sludge that the formation of fresh sludge pockets which may injure the digestion is practically eliminated. For five years we have continuously added daily 30 cubic meters of fresh solids to a 900 cubic meter tank and have had no difficulty from flies or odors on the drying beds.

3. The old sludge is more completely digested when mixed with fresh solids than when standing in layers. As much as 100 per cent increase in gas yield is obtained. The organic content of digested sludge which has been circulated is usually lower than in digested sludge which has stratified in a quiescent tank.

4. A thick layer of scum is broken up and digested by the vertical sludge mixing. Separate removal and drying of poorly digested scum is no longer necessary. The tanks do not foam.

5. The vertical mixing of sludge layers of various ages leads to an equalization of the pH value at about 7.3, so that lime is never necessary.

6. A uniform temperature throughout the entire tank can be maintained only by vertical mixing of the contents of the digestion room. This is especially important when the tanks are artificially heated.

7. The mixing apparatus can be removed from the tank for protection against corrosion without disturbing the digestion in the tank.

8. The maintenance of a colder sludge zone near the outer wall is not economical and is technically unreliable. A tank should be insulated by proper covering of the outside wall.

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[2] M. Prüss, "Instructions for Calculating the Size of a Digestion Tank," *Gesundh. Ing.*, 1928.

M. Prüss, "Progress in the Digestion of Sewage Sludge," published by R. Oldenberg, Munich and Berlin, 1928.

[3] H. Bach and F. Sierp, "Investigation of the Anaerobic Decomposition of Organic Matter by Bacteria from the Fresh Solids," *Zentralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten*, Part 2, **62**, 1924.

[4] M. Prüss, "Digestion Gas and Scum Treatment in Sludge Digestion Tanks," *Gesundh. Ing.*, 1930.

[5] F. Sierp, "Specific Heat, Conduction and Generation of Heat during the Digestion of Sewage Sludge," THIS JOURNAL, **2**, 191 (April, 1930).

[6] A. M. Buswell, G. E. Symons and E. L. Pearson, "Observations on Two-Stage Sludge Digestion," THIS JOURNAL, **2**, 214 (April, 1930).

Sludge Disposal at the Sewage Treatment Plant of Gelsenkirchen-Nord. H. BLUNK. *Gesundh. Ing.*, **53**, 246, April 19, 1930.—The sewage treated at Gelsenkirchen contains waste water from coal mines, iron works and chemical works. The Emscher tank plant opened in 1913 gave a satisfactorily purified effluent but the amount of sludge proved more than had been calculated, with the result that insufficiently digested sludge had to be drawn from the tanks to the drying ground. The effects of coal sludge in increasing the amount of sludge, of acid pickling liquors in increasing sedimentation, of the iron content of wastes in delaying digestion, and of the barium chloride in the chemical wastes in increasing sedimentation and impairing digestion, are briefly described. It was found that additional digestion room for 6700 cu. meter of sludge was necessary and it was decided that the requirement could be met by adding separate digestion tanks of 3600 cu. meter capacity with arrangements for heating and stirring the sludge. To minimize the danger due to earth movements caused by mining it was decided to build six 600 cu. meter tanks with steeply sloping conical floors, covers, and stirring arrangements. The construction is described and illustrated. The heat is supplied by thoroughly stirring in the previously heated fresh sludge. This is heated on its way from the Emscher tanks to the separate tanks by passing through pipes surrounded by hot water supplied from a boiler heated by methane gas. The operation of the plant has been entirely satisfactory. The results obtained at Worcester (Mass.) with the treatment of a similar sewage in Emscher tanks are described and the effect of a sewage with a very variable pH value on the operation of such a plant is discussed. The effect of the extra digestion of the sludge on the gas production at the Gelsenkirchen plant is also described. Abst. No. 1063, *British Summary of Current Literature, Water Pollution Research*, Vol. **III**, 9, Sept., 1930.

Sewage Filter Media and Loadings*

BY WM. E. STANLEY**

Sewage filters may be classified under two general types as regards the filter media:

1. Filters with coarse grain media, such as trickling and contact filters and
2. Filters with fine grain media, such as intermittent sand sewage filters and sludge beds. This discussion will be limited to the first type and particularly to the sewage trickling filters.

The development of sewage filters in this country began with the experiments by the Massachusetts State Board of Health in 1887. Similar experimental work was started a little later in England particularly in connection with the disposal of the sewage of London which at that time had a daily flow of 200,000,000 gallons.

The Massachusetts experiments at Lawrence have become classic and constitute the foundation of the development in the art of sewage treatment in this country. Many other installations of experimental sewage filters have been operated for relatively short periods of time at various places including Columbus, Philadelphia, Baltimore, Brooklyn, Cleveland, and others. More recently the results of operation of an experimental trickling filter have been published in Bulletin No. 26 of the Illinois State Water Survey.

A Committee on Filter Materials was appointed in 1925 by the Sanitary Engineering Division of the American Society of Civil Engineers. This committee has devoted its principal efforts to date to the question of the selection of trickling filter media from the view point of durability and has endeavored to develop laboratory and quarry inspection methods whereby comparisons can be made of the relative merits of two or more available materials with respect to probable durability under conditions of sewage filter operation.

Considerable data have been collected with reference to existing trickling filter installations and operation. Many laboratory tests have been made covering the physical characteristics of samples of filter material from selected trickling filter installations. During 1929 an elaborate series of soundness tests by the sodium sulphate solution method was completed by thirteen testing materials laboratories, in coöperation with the committee, for the purpose of checking up the laboratory procedure of the soundness test. The results of the investigations of the committee have been published from time to time in the *Proceedings of the American*

* *Presented at Meeting of Central States Sewage Works Association, Springfield, Ill., June 10, 1930.*

** *Sanitary Engineer, Pearse, Greeley and Hansen, Chicago.*

Society of Civil Engineers. The soundness test results will be published shortly.

Engineers, chemists and others who have to do with the development and operation of sizable sewage treatment plant projects are actively interested in questions of filter loadings and the relationships between the characteristics of filter media and loadings, and conditions of operation and loadings. These relate to a relatively complex subject about which there is much still to be learned.

Types of Materials

Various and sundry materials have been used as media in sewage trickling filters. Many of the earlier filters, particularly in England, were constructed of clinkers, cinders, coke or coal breeze. Excessive clogging and costs for cleaning have led to the use of more durable materials. An incomplete survey of trickling filters in the United States made in 1925 gave certain data on quantities of various materials used as filter media. These data indicate that 83 per cent of the filter media for the plants covered was crushed rock of one type or another, 2 per cent gravel, 11 per cent slag and most of the remaining 4 per cent cinders or coke. More complete data may modify these proportions somewhat but the general tendency in the past use of materials is indicated by the data available.

The harder and more durable materials such as crushed trap rock, quartzite and certain granites are the more desirable materials from the view point of durability. In the Central States area crushed limestone is the outstanding source of filter material.

In certain filters, the larger volume of material is made up of the cheaper local stone, while the top 12 inches or so is constructed with more expensive trap rock, granite or quartzite. This construction has been used at Lexington, Kentucky, at the southerly plant in Cleveland and elsewhere. At Lincoln, Nebraska, quartzite was shipped from a distance and used in preference to the local limestone because of the inferior character of the local stone as to durability.

Crushed slag as a source of filter media is being promoted rather actively by the slag interests particularly in certain sections of Ohio, Pennsylvania, and other eastern states where large quantities of slag are available. There are some engineers who appear to be somewhat reluctant to use slag, largely because of its roughness and the fear that it will not unload properly.

An extended study of the use of slag in sewage filters has recently been made by Charles C. Homman. His report has been published by the National Slag Association.[1]

[1] "Report of Investigation of Crushed Blast Furnace Slag as a Medium in Sewage Trickling Filters," C. C. Homman, National Slag Association, Cleveland, Ohio.

[1] SEWAGE WORKS JOURNAL, **2**, 387, July, 1930.

Surface roughness undoubtedly has some bearing on the efficiency of operation of filter media. Excessively rough honey-combed surfaces possibly tend to restrict unloading while unusually smooth surfaces might be detrimental by unloading too easily.

As yet little has been done to determine the effect of surface roughness. Further, no standard or accepted method has been devised to measure quantitatively surface roughness or the effect on surface area of shape irregularities. Kriege has attempted the measurement of surface area of limestone by comparing the loss of weight for a specimen in an acid bath to the loss by a sphere or cube of the same limestone in the bath for the same length of time.

A method of obtaining a definite quantitative measure of the irregularities or roughness of surfaces would be of value not only in the study of filter media but also in other phases of engineering work as, for instance, the interior condition of pipes with reference to the hydraulic losses.

Size and Gradation

The earlier sewage filters, particularly the English filters, included small sized material. Certain recent practice has tended toward large sizes. Usually the lower 6 inches or more of the filter bed is composed of fairly large stones carefully placed in order to protect against the entrance of fine material into the underdrains.

Typical practice in specifying the size of material for the upper part of the filter bed is indicated as follows:

Plant	Size Range of Top Filter Stone Screen Openings—Inches	
	Retained	Passing
Illinois		
Aurora	1	1 1/2
Bloomington	1	2
Decatur, Elgin, Urbana-Champaign	1	2
DeKalb		2
Other States		
Akron, O.	1	2 1/2
Baltimore, Md.	1	2 1/2
Brockton, Mass.	3/4	1 1/4
Canton, O.	1 1/2	2 3/4
Cleveland, O.	2	3
Columbus, O.	1 and 1 1/2	3
Fitchburg, Mass.	2	3
Lincoln, Nebr.	1/2	1
Madison, Wis.		
Old Plant	1/2	3/4
New Nine Springs Plant	1	2
Schenectady, N. Y.	1	2
Worcester, Mass.	1	3

There is a tendency to place rather strict limitations on the permissible amount of fine material of less than the smaller size specified in the filter material as furnished. At Akron 5 per cent was allowed less than the 1-inch size. At Hinsdale and at Jacksonville the amount of material less than 1 inch was limited to 3 per cent.

Selection and Testing

The selection of the general type of material to be used must be determined for any given installation based largely on judgment with reference to various local considerations. There are as yet insufficient data to set up definitely the relative merits of the various types such as crushed stone, slag, gravel and the like.

In the Central States area the use of crushed limestone has been practically universal. Accordingly this discussion will be related to the selection and testing of limestone filter material.

Limestone quarries usually include several layers of material, some of which may have inferior qualities as regards use in sewage filters. A very careful study should be made of the quarry conditions for the several possible sources from which the filter material may be obtained. This should include study of the geological characteristics, measurements of the thickness of the several stone strata, particularly in the vicinity where the material supply is to be obtained, and selection of samples for soundness and other physical quality tests.

Attention should be given to the crushing and screening facilities, particularly with reference to the equipment available to remove sizes of stone less than the minimum size specified.

The comparative physical qualities of the several proposed materials can be determined by laboratory tests and also by consideration of the experience in the use of material from the various quarries in filter plants which have been in operation.

Probably the soundness test is the most practicable laboratory test for the comparison of the merits of two or more materials as to probable durability. Such tests for soundness have been made in a number of cases by subjecting the material to alternate cycles of artificial freezing and thawing.

More recently a test has been developed by the committee on Filter Materials of the A. S. C. E. and others comprising cycles of alternate soaking in a saturated sodium sulphate solution and drying in an oven. The general idea of this test is not new, however much has been done during the past year or more to perfect the laboratory procedure of the test. This test is more severe than the freezing and thawing test and thus is a shorter test. Twenty cycles of the sodium sulphate test appear to be equivalent to possibly as many as 250 cycles of artificial freezing and thawing.

Other determinations of the physical qualities of the several possible materials are frequently useful. These include the determination of specific gravity, the absorption and porosity, chemical analysis with reference to certain impurities and micro-structural analyses by a qualified geologist.

Preparation and Placing

Many of the existing trickling filters, particularly the smaller installation, contain an excessive amount of fine material, much of which was included in the stone as originally placed. Unless special care be taken with the screening and handling of the material during construction it is likely that a greater quantity of fine material may be placed in the bed or may become segregated in localized areas than will result from deterioration over several years of exposure in operation.

It is a good practice to require sufficient screening, rescreening and care in handling so that a minimum amount of material will be included smaller than the smallest specified size.

At Decatur, Urbana and Elgin the contractor was required to rescreen the filter stone immediately before placing; at Elgin the stone was also washed.

Many of the stone quarries now are equipped or may be equipped with special screens of the horizontal vibratory type so that special rescreening of sewage filter material can be furnished at the quarry with a relatively high removal of fine material.

In placing the material care must also be exercised to prevent the segregation of the fines into localized areas. Thus if the material be transported by motor truck and placed by dumping directly into the filter bed there is a tendency to segregate an objectionable amount of the fines in the upper parts of the filter bed. In the case of at least one of the large sewage filter installations constructed in recent years the placing of material by belt conveyors has resulted in segregating fine material along the location of the conveyor to such an extent that a noticeable difference in surface clogging has been observed in operation.

Filter Depths

It appears to be more or less generally considered that trickling filters should be at least five to six feet deep. Recent trickling filter construction practice has tended toward deeper filters particularly in those cases where sufficient head is available or where pumping is required. Typical illustrations of the practice as to depth of filters in filter construction are as follows:

Place	Area Acres	Filter Depth—Feet
Akron, Ohio	14	10
Aurora, Illinois	3.6	6
Baltimore, Maryland	30	8.5
Bloomington, Illinois	2.5	8
Cleveland, Southerly Plant	6.0	10
Columbus, Ohio	10	5.5
Decatur, Illinois	3.0	6.5
Elgin, Illinois	1.5	8
Urbana-Champaign, Illinois	1.6	10
Fort Worth, Texas	3.0	9
Worcester, Massachusetts	14	10
Lincoln, Nebraska	2.6	6
Pontiac, Michigan	1.75	5.5

Numerous experimental filter installations have been constructed and operated for the purpose of determining the relative work done and efficiencies of filters having various depths of media. Unfortunately many of these experimental plants were not operated continuously for sufficient length of time to establish definitely the relation of depth and efficiency of operation.

Operation of test filters at Baltimore, Worcester and Brooklyn seem to indicate economies in filters of greater depth than 6 feet. The Baltimore tests covered a relatively short period, but the results were used as the basis for the design and construction of the largest trickling filter installation yet constructed in this country.

The Brooklyn tests extended over longer periods of time and the analytical results appear to give rather definite indication of increased efficiency with increase in depth. The maximum depth used was 10 feet.

Rather extensive results are available covering the operation of experimental filters at the Lawrence, Massachusetts, testing station. Examination of these data by some investigators has led to the conclusion that there is economy in filters greater than six feet in depth. Other investigators appear to find contrary conclusions.

Buswell, Strickhouser, and others recently conducted a series of sewage filter tests on the Urbana-Champaign filter and on a small experimental filter, from the results of which they concluded that the rate of purification decreases with the depth of filter and that there is some doubt as to the wisdom of the construction of filters greater than 6 feet in depth.

Further investigations are required, particularly comparisons of the operation results of existing installations over a period of years, before final and definite conclusions can be obtained as to the relative merits of deep *vs.* shallow trickling filter beds.

Deep filters appear to produce greater nitrification than shallower

filters. In certain cases it may be well to keep the production of nitrates to a minimum.

Filter Loadings

Early investigations of the operation of sewage filters, particularly the Royal Commission studies in England and the Lawrence experiments, related primarily to domestic sewage. These and other similar investigations led to the development of trickling filter loadings expressed in terms of the volume of sewage. Many filters have been designed on the basis of around 2.0 million gallons per acre per day.

More recent investigations have related to the effect of industrial sewages and thus sewages with greater organic matter content. These studies have led to the consideration of filter loading in terms of organic matter or sewage strength.

A number of years ago Mr. S. A. Greeley indicated a method of designing trickling filters by considering the sewage strength in terms of the nitrogen content as well as the quantity.

More recently the design of filters, particularly for handling strong sewages including much industrial waste, has included consideration of the biochemical oxygen demand of the sewage. Particular attention to this method of establishing the loadings of filters has been given by Mr. Pearse, Dr. Mohlman and others in the Chicago Sanitary District; by Mr. Greeley and Dr. Hatfield at Decatur; and by studies at Fort Worth, Baltimore, Columbus and other places.

The principal function of a trickling filter is to satisfy the oxygen demand of sewages, accordingly it appears reasonable to measure the results of operation in terms of the reduction of the oxygen demand. "The biochemical oxygen demand test appears to furnish by far the most valuable information as to the behavior of the plants and the efficiency of the various devices used in sewage purifications" (quoted from *U. S. P. H. S. Bulletin*, **132**, p. 31).

The determination of the relation of loading to efficiency of a filter presents a rather complicated problem which has not been solved as yet. Many factors appear to influence the relation of loadings and filter efficiency. Hatfield has recently classified these factors under two groupings.

I—*Structural Variables* (Design)

(*a*) Depth of Filter

(*b*) Type of underdrain and ventilation.

(*c*) Length of dosing and rest periods.

(*d*) Size, shape and kind of filter material.

II—*Physiological Variables* (micro-biological growth)

(*a*) Quantity of food for growth, or concentration.

(*b*) Quality of food, or kind of organic matter.

(*c*) Concentration of air or ventilation.
(*d*) Temperature of sewage.
(*e*) Toxic chemicals in sewage.

The work done by a sewage filter involves both relatively short time intervals and also relatively long time intervals. The passage of the sewage through the bed takes place in a comparatively short time, during which the organic sewage materials are reduced. On the other hand, the building up of the microbiological growth on the filter media may be a matter of considerable time. Thus a study of efficiencies related to variations in strength of the applied sewage may possibly indicate quite different results, if the variations include short time intervals such as occur from day to day, than would be the case if long periods be considered such as a week, a month or perhaps even a series of months.

Thus a study of the relation of the B. O. D. strength of the applied sewage to the per cent removal based upon variations in strength, which occur from day to day or extend over short periods of time for a number of filter plants, appears to indicate that the per cent removal of B. O. D. is constant, *i. e.*, the amount of B. O. D. in the effluent of the filter is directly proportional to the amount of B. O. D. in the effluent.

On the other hand results of the operation of filters at Decatur and Fort Worth with heavy B. O. D. loadings for comparatively longer periods of time appear to indicate that there is a maximum upper limit of applied B. O. D. load which can be handled successfully and any heavier load will result in decreased efficiency.

The Decatur filters have produced a removal of B. O. D. upwards of 5000 pounds per acre per day with sewage of relatively high strength (400 to 600 p. p. m. B. O. D.) before installations of pre-aeration. At Fort Worth with somewhat less efficient sewage distribution, removals of upward of 4700 pounds per acre per day were obtained. At both places low nitrates in the effluent appeared to indicate maximum load conditions.

Further study of this question of filter loadings will be required. Long term and continuous records of filters operating close to their upper limit should give more valuable data from which to determine the relative effect of the various factors which enter into the question than isolated analyses or short term records of filter operation, particularly if such filters are lightly loaded.

Operation Considerations

The operation of sewage trickling filters frequently requires considerable attention and work to keep the filters clean, particularly where the filters are loaded rather heavily or are handling industrial wastes. Frequent troubles are experienced such as clogging, fly nuisance and sometimes odor nuisance. All of these usually relate to excessive growths on the filter-

stone and are materially reduced, if not entirely eliminated, if the filters are kept clean.

The cleaning of filters and reducing of clogging is accomplished by various means, perhaps the most common being the breaking-up of surface growths by forking or harrowing or by cutting out a portion of the filter and allowing it to dry out. Flooding is sometimes resorted to, particularly for fly control.

Mr. E. E. Smith has described experiences in solving clogging troubles at Elgin by the use of chlorine and hosing.[1] Chlorination for the removal of excessive growths has been used at a number of places, for instance at Lackawanna, Schenectady and elsewhere.

There have been a number of instances where sewage filter beds have been kept clean by insects, particularly the insect *Achorutes Viaticus*, sometimes called *Podura*. These insects appear to live on the colloidal growth in the filter and remove the slimy gelatinous growths which cause clogging or ponding troubles. These insects have been found in the Madison filters of the Burke plant and I understand that Mr. Mackin has transplanted them to the filters of the New Nine Springs Plant.

There is a small booklet titled *Insect life on Sewage Filters* by Parkinson and Bell which describes the activities and experiences with the insect *Achorutes Viaticus* in several English filters. Several other references to the activities of the insect occur in the engineering literature. Dr. Rudolfs states that the insect has been put into the trickling filters at Schenectady and Plainfield. Mr. Smith has made an attempt to place them in the Elgin filters.

It is claimed that the filters which have the *Achorutes Viaticus* in them never are troubled with *Psychoda* fly. This should be a good recommendation for the *Achorutes Viaticus*, if true.

Chert Gravel as Sewage Filter Stone*

By J. E. Lamar**

The stone in trickling filters is subject to solution by the sewage, to marked temperature changes, and, in latitudes having a cold winter season, to severe frost action continued through several months. If, under these conditions, the filter stone fails and breaks into small pieces the sewage and the organic growth, which develops on the beds and sloughs off periodically, cannot pass through the filter beds freely and "pooling" or ponding may result. This decreases the efficiency of the filter and often necessitates replacement of the disintegrated stone with new sound material. At the present time limestone, dolomite, quartzite, gravel, granite, trap, and slag are commonly employed as media for trickling filters.

Chert Gravel.—In southern Illinois there is a rock formation 200 to 300 feet thick which is composed principally of chert, also called flint. This formation is known as the Clear Creek chert and is one of the older rock formations of the State, belonging to the Devonian system. The chert apparently at one time contained some limestone or calcareous material which has subsequently been removed, leaving it locally porous. In the region where the Clear Creek formation outcrops the streams have developed from it considerable deposits of chert gravel. This gravel has in a sense undergone natures' soundness test, having been subjected to freezing and thawing, heating and cooling and the dissolving action of water for periods of time to be reckoned in tens and possibly in hundreds of years. During the formation and transportation of the gravel the weaker, unsound chert has been broken into fine fragments leaving principally only the strong, relatively sound chert in sizable pieces.

In western Illinois, especially Calhoun County and parts of the adjoining counties, a similar gravel has been developed from the cherty Burlington limestone which is Mississippian in age. The amount of gravel available in some stream valleys is probably quite large.

Chert is composed essentially of silica (SiO_2) and, therefore, is practically insoluble. It is very hard, rather brittle and breaks with a relatively smooth, sharp, conchoidal fracture. The insolubility and hardness of this material made it appear to be an ideal filter stone if it were not too porous and brittle to withstand frost action and temperature changes, nor too smooth to prevent the animal and plant life, which feed upon and decompose the sewage, from obtaining good hold upon it. Furthermore, the great quantities of this material available in southern and western

* *Published by permission of M. M. Leighton, Chief, Illinois State Geological Survey, Urbana, Illinois.*

** *Geologist in Charge, Non-Fuel Products Studies, Illinois State Geological Survey.*

Illinois by mere loading, washing and screening, without the blasting and crushing commonly involved in the production of filter stone, favor its use as a filter stone in these regions.

Clear Creek Chert Gravel as Filter Stone.—In order to determine the value of the chert gravel as filter stone, the Illinois Geological Survey secured a cubic yard of this material from the vicinity of Alto Pass in southern Illinois. Through the coöperation of Dr. A. M. Buswell, Chief of the State Water Survey, and Mr. Gus H. Radebaugh of the Sanitary District of Champaign-Urbana, this test sample of chert was placed in the filter bed of the Champaign-Urbana sewage treatment works in June, 1924, during the construction of the plant. The stone was put in a wooden crib 3 by 3 by 3 ft., so placed as to be under severe operating conditions (Figure 1). All of the chert was less than $2^1/_2$ in. and more than $1^1/_2$ in. in size when shipped to the plant; some slight breakage may have occurred in transit.

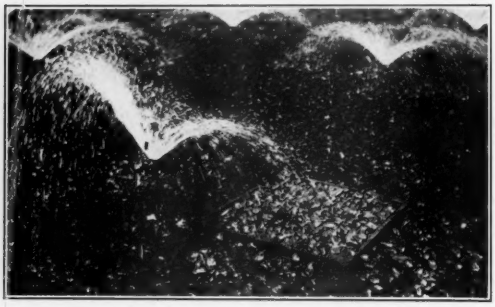

FIG. 1.—The Relation of the Crib to the Sprinklers.

The treatment works of Champaign-Urbana serve a community of 38,400 people. An average of about 3,500,000 gallons of sewage is treated daily. The filters are 10 ft. deep.

In June, 1929, five years after its installation, the chert was removed from the filter bed. During its life in the bed the chert gave entirely satisfactory service. Pooling did not occur and a good biological growth was supported. The chert appeared to be equally as efficient as the limestone which composes the filter bed proper, although a noticeable cracking and splitting of the surficial chert was apparent during the last three years of the five-year period, which might in time have caused "pooling," especially as a heavy coating of green algal material was present on the surface (Figure 2).

When the chert was removed in 1929 it was taken out in four portions or layers, 7, 7, 6 and 13 inches thick, respectively. A settling or compaction of three inches had occurred (Figure 2). The chert throughout the entire depth of the crib was unaffected by solution; no chalky exterior was developed and the stone appeared in every way as fresh as when placed in the crib 5 years previously (Figure 3). It is noteworthy that the disintegration of the chert which failed took place principally by

shattering or splitting of individual pieces rather than by the spalling off of small chips, although a minor amount of chipping had occurred in the surface of the bed.

Each of the four samples was screened to five sizes, which are shown in Table I, together with the results of the sieve tests.

Results of Sieve Tests.—Examination of Table I shows that both the weight and volume of the gravel retained on the 2-inch sieve was very nearly the same in all four layers of stone removed. This grade was composed entirely of chert which was not affected during its stay in the filter. The average amount of this stone present was about 45 per cent.

The amount of 1-inch grade was about the same in the two upper 7-inch beds, the average being 41 per cent by weight and 39 per cent by volume. In the lower 19 inches there was a notable increase, the average being 49.1 per cent by weight and 49 per cent by volume.

The material which passed the 1-inch screen was doubtless the product resulting from the disintegration of the stone, together with some small material resulting from breakage in transit.

The average amount of stone retained on the $^1/_2$ in. screen in the upper 14 inches and lower 19 inches of the bed were 12.0 per cent by volume and 10.2 per cent by weight, and 5.7 per cent by volume and 4.6 per cent by weight, respectively. Here there was a notable decrease in the amount of this grade in the lower part of the crib as compared with the upper portion.

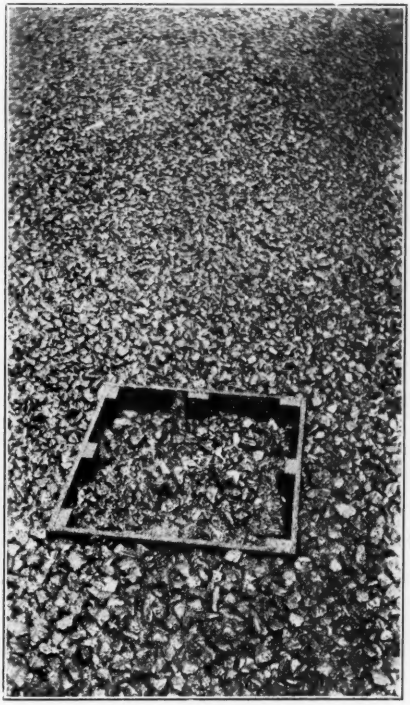

FIG. 2.—Chert Gravel in Crib as It Appeared after Five Years of Service. Note the Algal Growth Both in and outside the Crib.

The same general relations as shown for the $^1/_2$-in. grade were found for the $^1/_4$-in. grade.

Gravel passing the $^1/_4$-in. sieve constituted a very minor part of the

TABLE I

RESULTS OF SIEVE TESTS ON CHERT FROM CRIB IN FILTER BED OF CHAMPAIGN-URBANA SANITARY DISTRICT SEWAGE TREATMENT WORKS

Depth at Which Sample Was Taken	Sieve	Per cent Retained by Volume	Per cent Retained by Weight	Weight per Cubic Foot, Pounds
0–7 inches	2″	46.6	45.2	
	1″	37.2	41.0	
	1/2″	12.9	11.5	85
	1/4″	2.7	1.9	
	Pan	0.5	0.3	
		99.9	99.9	
7-14 inches	2″	45.2	47.9	
	1″	40.8	40.9	
	1/2″	11.1	8.9	71
	1/4″	2.3	1.7	
	Pan	0.6	0.6	
		100.0	100.0	
14–20 inches	2″	44.2	44.0	
	1″	47.4	48.7	
	1/2″	7.1	5.8	92
	1/4″	1.2	1.1	
	Pan	0.5	0.4	
		100.4	100.0	
20–33 inches	2″	45.8	46.5	
	1″	49.5	49.5	
	1/2″	4.2	3.3	96
	1/4″	0.4	0.5	
	Pan	0.1	0.1	
		100.0	99.9	

samples. The amount of this material in the lower 13 inches of the crib was very small, 0.1 per cent.

Conclusions

The data presented herewith, although based on only one test, suggest the tentative conclusions listed below, which may serve as a basis for further investigation in this field. It is to be emphasized that the conclusions do not apply to chert generally but rather to natural chert stream gravel

which has undergone weathering and abrasive processes that have largely eliminated the less resistant material.

1. The upper 20 inches of chert gravel in the test crib could probably not be considered to have become ineffective filter stone at the end of the test, but there were indications that under continued service it would have failed.

2. On the basis of this test the maximum breakage of chert filter stone will probably be found to occur normally in approximately the upper two feet of a filter bed in a region where climatic conditions are similar to those of central Illinois.

3. Chert gravel will support a good biological growth and is not materially affected by solution.

FIG. 3.—Chert Gravel from Depth of Two and One-Half Feet below Top of Filter Bed after Five Years of Service.

4. Chert gravel will probably give satisfactory results in that part of a filter more than three feet from the surface of the bed, but does not appear to offer great possibilities as a surface stone for trickling filters.

Correlation between B. O. D. and Suspended Solids of Activated Sludge Effluent[1]

BY H. GLADYS SWOPE[2]

The effluent from the activated sludge process at its best contains comparatively small amounts of suspended matter, but when the sludge bulks, or there is a rather sudden increase in rate of flow, the sludge floc in the final settling tanks may rise to the effluent weir and considerably larger amounts of suspended matter may be discharged temporarily. It is quite common for suspended matter to increase from 10 to 50 p. p. m. or more under such conditions and such an increase might be extended over 24 hours or longer. It has seemed of interest to determine what effect an increase in such suspended matter might have on the B. O. D. of an activated sludge effluent.

Anyone who has made a study of the analysis of activated sludge effluent is impressed by the fact that a two- or three-fold increase in suspended matter of the effluent does not show a relative increase in 5-day B. O. D.; in fact, under such conditions there is usually a very slight increase in 5-day B. O. D. It is recognized, however, that the 5-day B. O. D. is only a small proportion of the total oxygen requirement of the suspended solids, which may require oxygen for very long periods extending up to several hundred days. It seems probable that the 5-day demand does not indicate the extent of this continuing demand of the sludge particles. In order to obtain a little more information about these relations a few experiments have been made with samples of the activated sludge effluent from our North Side Treatment Works. Incubation has been carried out to 20 days at 20° Centigrade.

Experimental Procedure

The effluent was collected from the final settling tanks. As this effluent contained only 5 to 10 p. p. m. of suspended solids, and concentrations up to 50 p. p. m. or more were desired, it was necessary to collect the sample from the lower part of the tank in order to obtain more suspended solids. Five gallons of this effluent were settled for an hour or more. The supernatant liquor was siphoned over and filtered through cotton to remove most of the suspended matter. The amount of concentrated solids was determined by the Gooch crucible method. The calculated amount of this concentrate was added to each of five one-gallon bottles containing the filtered effluent in order to obtain, as closely as possible, effluents containing 10, 20, 30, 40 and 50 p. p. m. of suspended matter. Suspended

[1] *Presented at the Third Annual Meeting of the Central States Sewage Works Association, Springfield, Ill., June 10, 1930.*

[2] *Assistant Chemist, The Sanitary District of Chicago.*

solids were determined on each of the gallon samples including the filtered effluent.

The dissolved oxygen in each of these samples was determined by the Rideal-Stewart (permanganate) modification of the Winkler method. The dilution method was used for obtaining the biochemical oxygen demand. Distilled water containing 500 p. p. m. sodium bicarbonate was used as the diluting water. Oxygen demands were run in duplicate at intervals from one to twenty days at 20° Centigrade.

Thirty-four tests were made during July and August, 1929.

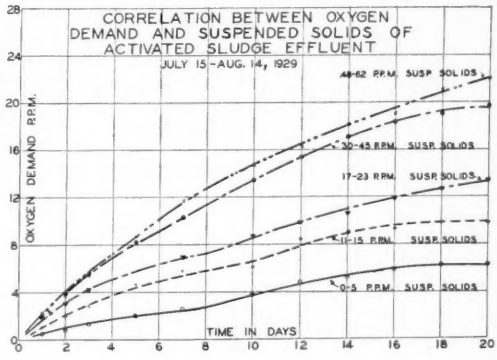

FIG. 1.

The sewage at the North Side plant at this time was very completely treated and the effluent contained 5.0 p. p. m. nitrate nitrogen which is considerably higher than the present nitrate content of the effluent. The effluent then contained only from 5 to 10 p. p. m. suspended solids, somewhat less than the usual content of from 10 to 20 parts per million.

TABLE I

BIOCHEMICAL OXYGEN DEMAND OF ACTIVATED SLUDGE EFFLUENT CONTAINING VARIOUS AMOUNTS OF SUSPENDED SOLIDS

	Biochemical Oxygen Demand Parts per Million				
Days Incubated	Seven Results Range from 0.0–5.0 P. p. m. Susp. Solids Av. 2.3 P. p. m.	Five Results Range from 11–15 P. p. m. Susp. Solids Av. 13 P. p. m.	Five Results Range from 17–23 P. p. m. Susp. Solids Av. 21 P. p. m.	Ten Results Range from 30–45 P. p. m. Susp. Solids Av. 39 P. p. m.	Seven Results Range from 48–62 P. p. m. Susp. Solids Av. 57 P. p. m.
1	0.5	1.1	1.8	2.0	2.2
2	0.8	2.0	3.1	3.9	3.8
3	1.3	2.8	4.2	5.6	5.5
5	2.0	4.7	5.7	8.2	8.7
7	2.6	5.8	7.0	10.3	11.7
10	3.8	6.1	8.7	13.4	14.6
12	4.8	8.4	9.9	15.4	16.2
14	5.2	9.0	10.6	17.1	18.1
16	5.9	9.3	11.9	18.3	19.0
18	6.2	9.8	12.7	19.0	21.0
20	6.3	9.8	13.5	19.7	22.0

Table I shows the B. O. D. obtained over the period from one to twenty days for an average of 2.3, 13, 21, 39, and 57 p. p. m. of suspended solids. These results are represented graphically in Figure 1.

Discussion of Results

It is practical in routine laboratory work to determine only the 5-day B. O. D. In studying these results as given in Table I, the actual increase in parts per million per increase in suspended solids is very low. For instance, when the solids increase from an average of 2.3 to 13 p. p. m., an increase of 10.7 p. p. m., the corresponding increase in 5-day B. O. D. is only 2.7 parts per million. Likewise when the average solids increase is from 13 to 21, 21 to 39 and 39 to 57, an increase of 8, 18 and 18 p. p. m., respectively, the corresponding increase in the 5-day B. O. D. is only 1.0, 2.5 and 0.5 p. p. m. The corresponding increase in 10-day B. O. D. is 2.3, 2.6, 4.7 and 1.2 p. p. m. and the 20-day B. O. D. increase is 3.5, 3.7, 6.2 and 2.3 p. p. m., respectively.

In order to estimate the importance of these relations, the rate of increase should be compared with the samples containing an average of 13 p. p. m. suspended solids since this is a representative effluent. Considered on this basis the overall increase in B. O. D. for an increase of 13 to 57 p. p. m. suspended solids is shown in Table II. These results

TABLE II

EFFECT OF INCREASE OF SUSPENDED SOLIDS ON THE B. O. D. OF ACTIVATED SLUDGE EFFLUENT

Days	B. O. D. of Activated Sludge Effluent Containing 11–15 P. p. m. Susp. Solids, Av. 13 P. p. m.	B. O. D. of Activated Sludge Effluent Containing 48–62 P. p. m. Susp. Solids, Av. 57 P. p. m.	Increase in B. O. D. (P. p.m.) with Average Increase in Susp. Solids of 44 P. p. m.	Per Cent Increase in B. O. D. with Average Increase of 44 P. p. m. Suspended Solids
2	2.0	3.8	1.8	90%
5	4.7	8.7	4.0	85%
10	6.1	14.6	8.5	139%
20	9.8	22.0	12.2	125%

show that: (1) The 5-day B. O. D. increases from 4.7 to 8.7 p. p. m., a percentage increase of 85%; (2) the 10-day B. O. D. increases from 6.1 to 14.6 p. p. m., or 139%; and (3) the 20-day B. O. D. increases from 9.8 to 22.0 p. p. m., or 125%.

As the time of incubation is lengthened the relative increase of B. O. D. is greater; this is logical in view of the presumably slow rate of oxygen requirement by suspended solids, and these results indicate that this effect is not shown by the routine 5-day results.

An increase from 4.7 to 8.7 is not serious and the effluent might still be considered to be quite satisfactory; but an increase from 9.8 to 22.0 p. p. m.

is of greater importance and the effluent would require oxygen during disposal for a much longer period than indicated merely by 5-day results.

Further studies are to be made on activated sludge effluents from our Des Plaines Treatment Works.

The author wishes to express her appreciation of the assistance of Dr. F. W. Mohlman under whose direction the work was carried out.

Studies of Biochemical Oxygen Demand of Trade Wastes.—E. F. ELDRIDGE. *Eng. News Record*, **105,** 12–13, July 3, 1930. The usual two-stage type of curve of oxygen consumption, which holds for sewage, is not always applicable to industrial wastes. Experiments at the Engineering Experiment Station, East Lansing, Michigan, were made with wastes from paper mills, milk plants and beet-sugar factories. Five series of samples were used for each waste. The diluted samples were incubated at 20° C., with determination of residual dissolved oxygen up to 25 days. Calculated B. O. D. results were plotted.

The curves for sulphite liquor and white water from paper mills show quite different rates, with an apparent transitional stage for the former in 5 days and a slow transition for the latter in 12 days.

Milk wastes gave a two-stage curve similar to sewage, with the transition occurring somewhat earlier, in 8 to 10 days, probably on account of the rapid oxidation of milk sugar in a medium with a high pH, approximately 7.6.

Sugar-beet wastes were collected from five sources: (1) flume water, mostly washings, beet tops and roots; (2) battery wash water from the diffusers, containing some sugar and nitrogenous matter; (3) lime pond water, very alkaline, but of moderate organic content; (4) pulp press water, containing sugar and a large amount of organic matter; and (5) Steffen's waste, the most concentrated, containing most of the extractable substances except sugar. Wastes 1, 2 and 3 showed some tendency toward two-stage curves, with the transition occurring from the 10th to the 18th day. Wastes 4 and 5, far more concentrated, show no appreciable second stage in 25 days.

The results as a whole indicate that the first stage is followed fairly closely by all wastes but that the second stage may occur at various periods or not at all, dependent on the composition of the wastes.

Effect of Iron on the Anaerobic Decomposition of Sewage Solids*

BY L. R. SETTER**

Occasionally there appears in the literature of late years the possibility of a catalytic effect of iron compounds on the digestion of sewage solids. The evidence for such a belief is based largely on the particularly good behavior of digestion tanks receiving industrial wastes such as tannery wastes and steel mill pickling liquors, which have a high iron content. In addition to the iron of industrial wastes most of the more efficient precipitants used to increase sewage purification contain either iron or aluminum.

The various constituents of sewage solids with which we are dealing are very complex in nature. How much more complex is a mixture of these constituents! With such a mixture the theoretical effect of iron compounds on the anaerobic decomposition of such solids resolves itself into two possibilities, each depending on a number of factors. The possibilities are:

1. The physical combination of the above constituents and the physical and chemical combination of their intermediate products of decomposition with either the cation or anion of the iron compound, resulting in a change of the biological action.

2. The effect of either the anion or cation of the iron compound on the organisms responsible for the decomposition.

The Collection of Fresh Solids.—The fresh solids used in the following experiments, with the exception of those used in experiment No. 4, were obtained from the Imhoff tanks functioning as sedimentation tanks of the Plainfield–North Plainfield–Dunellen Joint Disposal Plant. Three pails were sunk 5 feet from the surface, one at either end and one in the middle of the flowing-through chamber. The solids collecting in these pails after 24 hours were concentrated by decantation and then combined. This method of collecting the fresh solids insured a representative sample of the coarser and finer particles in the sewage.

The fresh solids used for experiment No. 6 consisted of the solids collected from the discharge of the sludge pump of the Dorr Clarifier at the Ridgewood Sewage Disposal Plant, Ridgewood, New Jersey. The solids were not more than three hours old.

In all experiments the solids were relatively fresh and primarily from domestic sewage.

The Collection of Ripe Sludge.—The ripe sludge used for seeding the fresh solids consisted of the ripe sludge drawn from the Plainfield separate

* *Excerpts from a thesis for degree of Master of Science, Rutgers University, New Brunswick, New Jersey.*

** *Research Fellow, Department of Sewage Disposal.*

sludge digestion tank and stored at room temperature in the laboratory for 1 to 2 months.

Mixtures of ripe sludge and fresh solids were made in a 1 to 2 ratio. Solids, ash and pH values were determined at weekly intervals and gas collected daily. The gas was analyzed at intervals. Biochemical oxygen demand determinations were made by the direct oxygen absorption method.

Additions of Iron to Sludge Mixtures

The ferric chloride used in these experiments was a commercial product containing 23.5 per cent $FeCl_3$ as determined by gravimetric analysis. The solution of ferric chloride was added to the sludge mixture on the basis of raw sewage assuming 150 p. p. m. (dry) settleable solids. Referring to Table I the calculations of the $FeCl_3$ added as Fe per volume mixture are given. The commercial precipitants, 49 per cent $FeCl_3$, $Fe_2(SO_4)_3$, $Al_2(SO_4)_3$ and sodium aluminates were added in p. p. m. of salt on the basis of raw sewage assuming 150 p. p. m. (dry) settleable solids.

In comparing the effect of different forms of iron the various salts were added on the basis of equal concentration of iron.

The iron content of the fresh solids and ripe sludge was determined by the standard gravimetric method.

Experiment 1

The Effect of $FeCl_3$ on Digestion

From 0 to 20 p. p. m. of a 23.5 per cent $FeCl_3$ solution was added to a fresh solids–ripe sludge mixture on the basis of raw sewage assuming 150 p. p. m. dry settleable solids. The materials used in this experiment were analyzed, with results as follows:

	Solids, %	Ash, %	Volatile Matter, %	pH
Fresh solids	5.03	21.2	3.98	5.8
Ripe sludge	7.30	50.5	3.62	7.2
Mixture	5.80	35.4	3.72	6.8

TABLE I

AMOUNT OF $FeCl_3$ ADDED

23.5% Sol. of $FeCl_3$ on the Basis of Raw Sludge, P. p. m.	$FeCl_3$ as Fe on Basis of Sewage, P. p. m.	$FeCl_3$ as Fe on Volume of Sludge, Basis, P. p. m.	$FeCl_3$ as Fe on Basis of Ash Present, %
2	0.1623	32.7	0.171
5	0.4059	81.8	0.426
7.5	0.6086	122.6	0.64
20	1.623	327	0.71
40	3.246	654	3.42

The fresh solids and ripe sludge were mixed in a 2 to 1 ratio of volatile matter. Ferric chloride was added to 1540 grams of mixture corresponding to 1000 grams of fresh solids. One-half of the resulting mixture was used for gas production while the other half was divided into four 300-cc. capacity bottles which were incubated at the same temperature (22° C.) as the mixture used for gas production. At weekly intervals enough material was removed from the 300-cc. bottle to be used for analysis and the remainder of the material discarded.

Results

Table I shows the amounts of $FeCl_3$ added. The results of the anaerobic decomposition of sewage solids are given in Figures 1, 2 and 3.

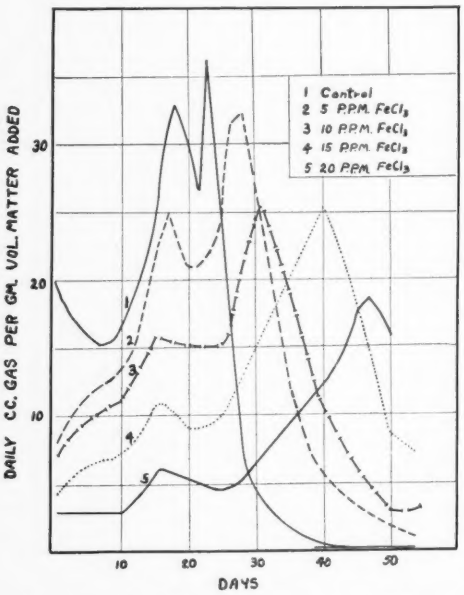

FIG. 1.—Daily gas production from mixtures for ripe sludge and fresh solids treated with different amounts of ferric chloride.

From Figure 1 it is noticed that 5 p. p. m. $FeCl_3$ or more had a marked effect on the normal two-stage digestion curve. The peak of gasification for $FeCl_3$ treated sludges was shifted to the right and lowered in direct proportion to the amount of salt added. Quantities of $FeCl_3$ less than 5 p. p. m. give a curve practically identical to the control for the first 23 days but the sudden decrease of gas production after the maximum peak in the case of the control was somewhat less for quantities of $FeCl_3$ up to 5 p. p. m.

It will also be noticed that the daily gas produced by the control decreased for the first seven days before the rapid rise occurred, whereas the daily gas of the iron-treated sludges began at a much lower figure and gradually rose. Peculiarly enough the first peak of gasification, although lower with increased iron concentration, occurred practically the same day in all cases.

More than 5 p. p. m. ferric chloride caused a marked retardation of gasification, which is shown better in Figure 2. Digestion of the control may be considered to be complete after 35 days but at that time 11.2 per cent more gas had been produced by sludge containing 5 p. p. m. $FeCl_3$. The digestion of 5 p. p. m. treatment was not complete until 50 days of digestion when 21.7 per cent more gas had been produced. After 54 days 7.5 per cent more gas was produced by 15 p. p. m. $FeCl_3$ treatment than the control.

The final reduction of solids, and volatile matter and increase of ash after a digestion period of 54 days was approximately the same for treatment up to 15 p. p m. ferric chloride. It will be seen from Figure 3 that the rate of reduction was more or less parallel to the rate of gasification.

The acidity of the $FeCl_3$ caused a lowering of the pH value of the mixtures. Recovery of the reaction occurred within the first week for treatments up to 10 p. p. m. Recovery of reaction occurred after 2 weeks in the case of 15 p. p. m. $FeCl_3$ and 3 weeks in the case of 20 p. p. m.

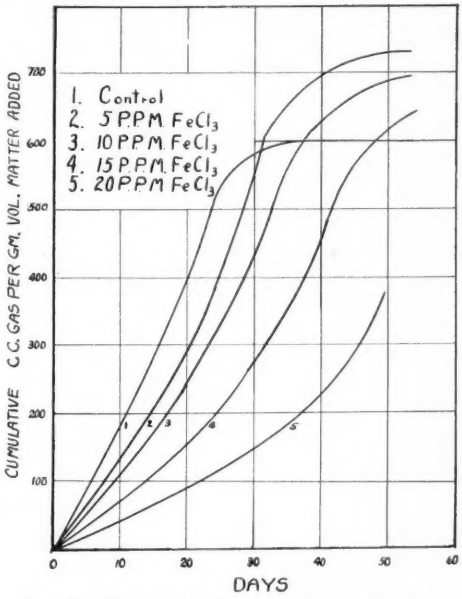

FIG. 2.—Gas production (cumulative) from mixtures of ripe sludge and fresh solids treated with different amounts of ferric chloride.

The reaction of the treated mixtures after 54 days was the same (pH 6.8) whereas the control had a pH of 7.6 indicating that the $FeCl_3$ had changed from its acid nature to an iron compound acting more as a buffer. However, since the reaction of all the mixtures varied so slightly its consideration is of minor importance.

In summary it can be stated that 1–4 p. p. m. $FeCl_3$ on the basis of sewage has no appreciable effect on digestion. Quantities of $FeCl_3$ greater than 4 p. p. m. cause a marked retardation of gasification proportional to the amount of $FeCl_3$, with the result that the digestion period is doubled upon the addition of 7.5 p. p. m. $FeCl_3$.

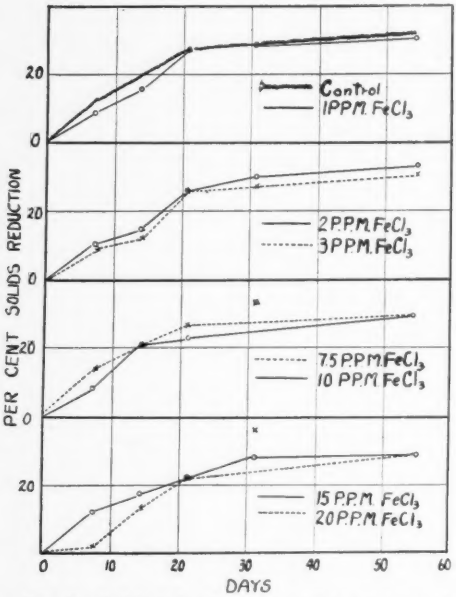

FIG. 3.—Solids reduction (per cent) in mixtures of ripe sludge and fresh solids treated with different quantities of ferric chloride.

Experiment II

The Effect of $FeCl_3$ on Digestion with Initial Reaction Control

In the preceding experiment a definite retardation of gasification resulted by the addition of relatively large amounts of $FeCl_3$. It was thought that the Cl^- ion upon the hydrolysis of the iron salt as well as the free HCl existing as a contaminant of the salt might play an important part in causing this retardation. Thus an experiment was made in which the reaction was adjusted to a pH of 7.3 at the beginning of digestion.

Preliminary adjustment of the reaction was secured by the addition of hydrated lime one hour after the $FeCl_3$ additions were administered. The amounts added were:

Treatment $FeCl_3$ P. p. m.	Lime Added Grams per Liter	pH Before	pH After
0	1.05	6.8	7.4
2	1.33	6.4	7.2
5	1.48	6.1	7.4
7.5	1.61	6.1	7.4
20	2.25	5.9	7.3
40	3.40	5.5	7.2

After the addition of lime it can be assumed that the iron was present as a mixture of hydrate, bicarbonate or to some extent as a chloride.

The analysis of the fresh solids, ripe sludge and the mixtures showed:

Treatment	% Solids	% Ash, Dry Basis	% Volatile Matter, Wet Basis	pH
Fresh solids	6.0	20.1	4.78	5.7
Ripe solids	7.42	50.7	3.65	7.4
Control	6.8	34.7	4.44	...
2 p. p. m.	6.72	34.4	4.40	...
5 p. p. m.	6.72	34.2	4.42	...
7.5 p. p. m.	6.26	34.4	4.10	...
40 p. p. m.	7.03	35.0	4.56	...

Results

The results obtained are graphically shown in Figures 4 and 5 and a condensed summary in Table II.

TABLE II

SOLIDS, ASH AND VOLATILE MATTER AFTER A 55-DAY DIGESTION PERIOD

Treatment	% Solids	% Ash, Dry Basis	% Volatile Matter, Wet Basis
Control	4.51	47.1	2.39
2 p. p. m. $FeCl_3$	4.57	47.8	2.39
5 p. p. m. $FeCl_3$	4.80	51.9	2.31
7.5 p. p. m. $FeCl_3$	4.56	50.7	2.25
20 p. p. m. $FeCl_3$	4.62	48.1	2.40
After 66 days digestion			
40 p. p. m. $FeCl_3$	4.90	46.0	2.64

Again a definite retardation of gasification occurred as appeared without the reaction control, but the degree of retardation was not nearly so pronounced as in the preceding experiment. With increasing amounts of $FeCl_3$ the gas peak was proportionally lowered and occurred after a longer digestion period. On the whole the rate of gasification was more rapid with initial reaction control than without.

Again, the rate of gasification is decreased in proportion to the increase of $FeCl_3$ treatment. Except in the 40 p. p. m. $FeCl_3$ treatment, the solids reduction, volatile matter reduction and ash increase were approximately the same for the different treatments. The larger quantity, however, decreased slightly the solids reduction, volatile matter reduction, and ash increase.

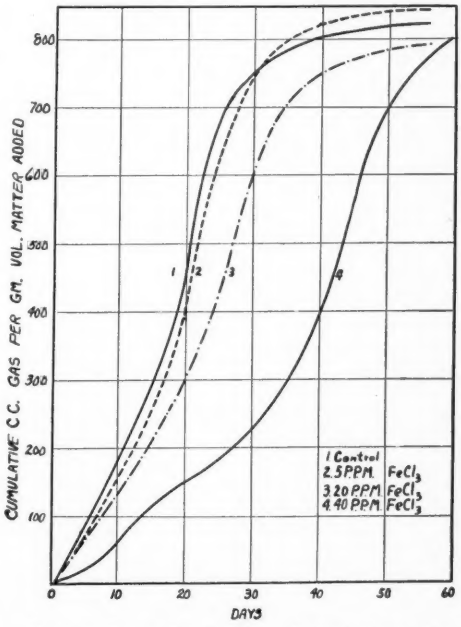

FIG. 4.—Gas production (cumulative) from mixtures of ripe sludge and fresh solids treated with lime and different amounts of ferric chloride.

The digestion period required for the control was 40 days, that of 20 p. p. m. $FeCl_3$ treatment 55 days and that of 40 p. p. m. 70 days, so that the

digestion period was doubled by the addition of 40 p. p. m. $FeCl_3$ against the doubling of the digestion period by 7.5 p. p. m. $FeCl_3$ without the initial reaction control.

Relatively large quantities of $FeCl_3$ added to seeded fresh solids, the reaction of which is controlled with hydrated lime, causes a retardation of gasification though not as marked as without pH adjustment. Except for relatively high quantities of $FeCl_3$ the reduction of the solids is the same. Large quantities of $FeCl_3$ decrease the reduction.

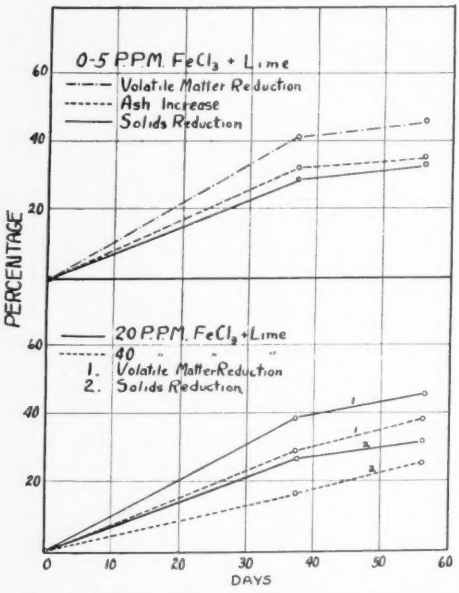

FIG. 5—Solids reduction, volatile matter reduction and ash increase in ripe sludge–fresh solids mixtures treated with lime and different amounts of ferric chloride.

Experiment III

Toxicity of Ferric Chloride to Bacteria

Since the bacterial population of the material under investigation is very high, it did not seem that the toxicity of the $FeCl_3$ would play an important part in the digestion because, even though partial sterilization is obtained, the rate of recovery of the microbial population would be extremely rapid as soon as the $FeCl_3$ is changed to some inactive state. In this respect the $FeCl_3$ undergoes reduction as soon as anaerobic conditions are established and the iron will be largely in the ferrous state. This was shown by Starkey and Halvorson[1] in 1927.

TABLE III

Material	Numbers of Bacteria/Cc. Average of 3 Plates
Control	13,200,000
5 p. p. m. $FeCl_3$	15,500,000
10 p. p. m. $FeCl_3$	3,600,000
20 p. p. m. $FeCl_3$	240,000*

* Largely fungi.

Nevertheless an experiment was made to determine the toxicity of

$FeCl_3$ on the organisms in fresh solids. The results of this experiment are given in Table III in which the numbers of organisms were determined on meat extract-peptone-agar plates after one hour of $FeCl_3$ treatment.

As in the two previous experiments the $FeCl_3$ solution was added in p. p. m. to the fresh solids on the basis of raw sewage assuming 150 p. p. m. dry settleable solids.

Over 98 per cent of the total microbial population in fresh solids are destroyed by 20 p. p. m. $FeCl_3$ treatment. The remaining 2 per cent are fungi which play a more or less insignificant rôle in the anaerobic decomposition of sewage solids.

Five p. p. m. $FeCl_3$ caused a slight increase of bacterial population whereas 10 p. p. m. $FeCl_3$ caused a 20 per cent reduction.

Relatively large quantities of $FeCl_3$ are decidedly toxic to the organisms present in fresh solids whereas 5 p. p. m. $FeCl_3$ or less has very little effect.

Experiment IV

Oxygen Demand of Fresh Solids

In order to obtain further light on the subject of the effect of iron in the activated sludge process of purification, an attempt was made to solve the biological problem by determining the biochemical oxygen demand by

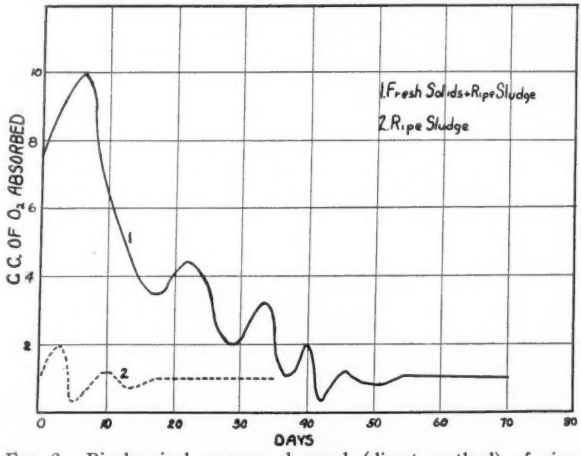

FIG. 6.—Biochemical oxygen demand (direct method) of ripe-sludge and fresh-solids mixtures during the course of digestion.

the direct absorption method. Actually this method consists of supplying a potential oxygen tension so that the decomposition is purely aerobic and the rate of decomposition or stabilization can be measured by the amount of oxygen consumed.

There was no difference in the rate of oxygen consumption by $FeCl_3$ treatment nor was there any difference in the total quantity of oxygen required per gram of volatile matter added after all the organic material had become relatively stable (Table IV).

TABLE IV

$FeCl_3$ Treatment, P. p. m.	Oxygen Absorbed in 64 Days, C. c. s.	Vol. of 1% Solids in 500 P. p. m. $NaHCO_3H_2O$, Grams	Wt. of Vol. Mat. Added, Grams	O_2 Absorbed per Gram Vol. Added, Grams
0	213.5	435	0.1110	2.54
2	204.5	418	0.1070	2.52
5	200.0	456	0.1170	2.26
10	225	421	0.1075	2.76
20	206.5	415	....	..

Figure 6 shows the general character of the B. O. D. curve regardless of the $FeCl_3$ treatment up to 20 p. p. m.

It is interesting to note that the oxygen requirement per capita per day

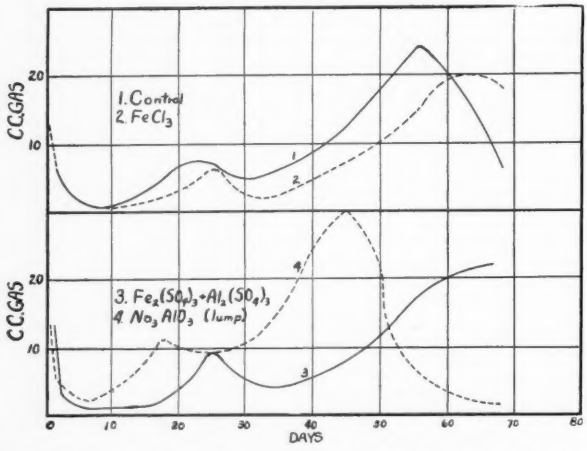

FIG. 7.—Daily gas production from ripe sludge–fresh solids mixtures treated with certain commercial precipitants.

is somewhat higher than Theriault's[2] figure which is obtained by the dilution method. From Figure 6 it is shown that the organic matter is fairly stable after 35 days or that aerobic decomposition is as rapid as anaerobic decomposition. After this period the B. O. D. of ripe sludge will be measured. It will be seen that 2.0 grams of oxygen are required per gram of volatile matter added, and assuming 70 grams of dry solid or 50 grams of volatile matter per capita per day we find that 100 grams of oxygen are required per capita per day.

Ferric chloride up to a concentration of 20 p. p. m. has no effect on a 64-day B. O. D. of sewage solids.

The per capita per day oxygen requirement by the direct oxygen method is in fairly good agreement with Theriault's estimate.

Experiment V

The Effect of Certain Commercial Precipitants on Digestion

The effect of 5 p. p. m. of four commercial precipitants (49% $FeCl_3$, a mixture of sulphates of iron and aluminium, a solution of sodium aluminate (K. W. S. No. 2), and crude sodium aluminate (lump), on the digestion of sewage solids was studied. The results obtained have been plotted in Figures 7 and 8.

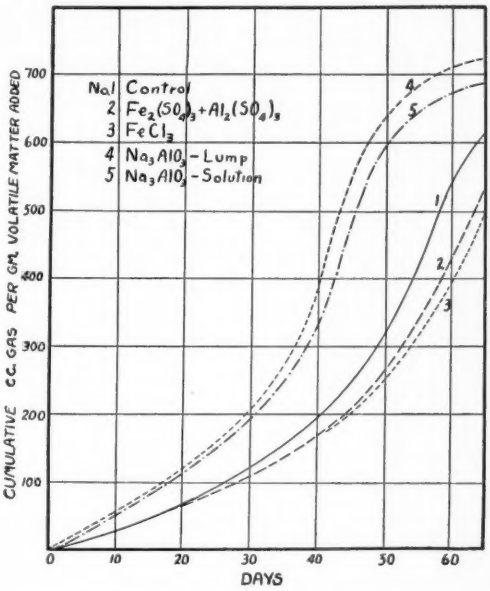

FIG. 8.—Gas production (cumulative) from ripe-sludge, fresh-solids mixtures treated with certain commercial precipitants.

The analysis of the fresh solids, ripe sludge and mixtures was as follows:

Treatment	% Solids	% Ash, Dry Basis	% Volatile Matter, Wet Basis	pH
Fresh solids	5.7	20.0	4.58	6.8
Ripe sludge	7.31	53.0	3.42	7.9
All mixtures	6.30	36.0	4.04	...

The fresh solids were found to be very abnormal which is shown by the digestion of the control. With normal fresh solids the peak of gasification occurs within 12–20 days and digestion is complete within 35 days; however, in this particular experiment the peak of gasification did not occur until 56 days and digestion was not complete until 70 days.

Bearing in mind the abnormality of the fresh solids, some interesting results can, nevertheless, be brought out in this experiment by comparing the digestion of the different salt treatments with the control.

The two sodium aluminates caused an increase in the rate of gasifi-

cation (Curve 4, Figure 7).† The first gas peak was reached 5 days before the first gas peak of the control, and a difference of 11 days exists between the second gas peak (Figure 7). The digestion of the sodium aluminate treated sludges was complete in 52 days whereas the control was not digested until 67 days. In other words 5, p. p. m. of the Na_3AlO_3 caused a 20 per cent decrease in the digestion period.

The $FeCl_3$ treatment and ferric aluminium sulphate treatment caused a marked retardation of gasification, the exact nature of which is shown clearly in Figures 7 and 8. The retardation of ferric aluminium sulphate treatment was somewhat less than the $FeCl_3$ treatment but in either case the digestion period was increased by 20 per cent.

Particular attention is drawn to the fact that regardless of the kind of salt treatment the solids reduction, ash increase and volatile matter reduction after 70 days of digestion was greater than that of the control (Table V).

TABLE V

SOLIDS, ASH AND VOLATILE MATTER AFTER A DIGESTION PERIOD OF 70 DAYS

	% Solids	% Ash, Dry Basis	% Volatile Matter, Wet Basis
Control	4.63	47.1	2.45
40% $FeCl_3$	4.74	45.6	2.58
FeAl aluminate	4.46	48.8	2.28
Na_3AlO_3 lump	4.49	48.7	2.53
Na_3AlO_3 K. W. S. No. 2	4.46	48.8	2.28

A condensed summary of the changes in solids and ash, together with the gas produced per gram volatile matter destroyed is presented in Table VI.

TABLE VI

Treatment 5 P. p. m.	Digestion Period, Days	pH	Solids Red., %	Ash Increase, %	Vol. Matter Red., %	Gas/Gm. Vol. Matter Destroyed, Cc.
Control	0	6.7	..	..	..	
	37	7.5	28.9	30.5	41.5	
	59	7.5	31.3	35.6	45.5	
	70	7.5	22.4	29.0	38.4	1670
49% $FeCl_3$	0	6.3	..	..	..	
	37	7.7	32.0	34.5	44.8	
	59	7.7	32.9	40.6	47.5	
	70	7.5	24.8	28.8	36.8	..
$Fe(SO_4)_2$	0	6.1	..	..	..	
$Al_2(SO_4)_3$	37	7.5	33.0	35.5	46.4	
	59	7.5	32.1	39.7	47.2	
	70	7.5	27.0	30.2	39.3	1580

† *Curve No. 4, Fig. 7 is the gas curve for Na_3AlO_3 (lump) which practically coincide with the Na_3AlO_3 solution curve not plotted. Curve No. 4 is compared to curve No. 1.*

TABLE VI (*Continued*)

Treatment 5 P. p. m.	Digestion Period, Days	pH	Solids Red., %	Ash Increase, %	Vol. Matter Red., %	Gas/Gm. Vol. Matter Destroyed, Cc.,
Na_2AlO_3	0	6.8	..	..	..	
Lump	37	7.8	33.8	34.5	46.8	
	59	7.7	31.0	40.5	47.3	
	70	7.5	22.1	34.2	37.3	1960
Na_2AlO_3	0	6.9	..	..	..	
K. W. S. No. 2	37	7.7	31.2	36.9	45.5	
	59	7.7	31.2	41.8	44.9	
	70	7.5	28.4	35.2	39.9	1720

Experiment VI

The Effect of Iron Compounds on the Digestion of Sewage Solids

The analysis of the fresh solids and ripe sludge used in this experiment was as follows:

	% Solids	% Ash, Dry Basis	% Volatile Matter, Wet Basis	pH
F. S.	5.87	29.9	4.11	5.8
R. S.	7.25	50.6	3.57	7.5

A 2–1 volatile matter ratio of fresh solids to ripe sludge was made and 1459 grams of the mixture was used for gas production. Two p. p. m. Fe as $FeCl_3$, $FeCl_2$, $Fe_2(SO_4)_3$, $FeSO_4$, basic iron acetate, ferric citrate, colloidal Fe_2O_3 and dialyzed freshly precipitated $Fe(OH)_3$ were added to each mixture on the basis of raw sewage, assuming 150 p. p. m. (dry) settleable solids.

After the addition of the iron compound an analysis was made of each mixture (Table VII).

Results

An inspection of Table VII and Figures 9 and 10 shows the following results.

1. $Fe(OH)_3$ caused a slight stimulation of gasification, approximately the same reduction of solids and volatile matter, and approximately the same ash increase as the control.
2. Fe_2O_3 and iron had no effect.
3. Iron citrate, $FeCl_2$, and $FeSO_4$ caused a slight retardation of gasification, gave a greater solids reduction, volatile matter reduction, and ash increase; especially was this the case of iron citrate.
4. Iron acetate produced an even greater retardation of gasification than did iron citrate though the solids reduction, volatile matter reduction, and ash increase was the same.
5. The two ferric salts, $FeCl_3$ and $Fe_2(SO_4)_3$, behaved in a similar manner.

TABLE VII

THE EFFECT OF IRON COMPOUNDS ON DIGESTION

Material	Days	Solids, %	Ash, %	Vol. Mat., %	Solids Red., %	Ash Incr., %	Vol. Mat. Destroyed, %	Gas/Gm. Vol. Ad., Cc.	Gas/Gm. Vol. M. D., Cc.	pH
Ferric	0	6.50	39.3	3.94	..	..	..	..	..	6.5
chloride	17	3.30	44.1	3.24	10.7	12.2	17.8	67.6	380	7.1
	30	4.65	43.3	2.42	28.5	22.9	38.9	120.0	309	7.5
Ferrous	0	6.50	39.4	3.93	..	..	..	..	..	6.6
chloride	17	5.40	48.6	2.77	18.9	23.4	29.0	223	770	7.3
	30	4.68	50.2	2.33	28.0	27.5	40.8	603	1480	7.5
Ferric	0	6.50	41.0	3.84	..	..	..	..	..	6.4
sulfate	17	5.80	45.1	3.18	10.7	10.0	17.2	56.0	326	7.4
	30	4.76	50.3	2.37	26.8	22.7	38.3	99	258	7.5
Ferrous	0	6.45	40.4	3.35	..	..	..	..	..	6.6
sulfate	17	3.28	49.4	2.68	18.2	22.3	30.4	238	785	7.2
	30	4.66	51.5	2.26	27.8	27.5	41.5	607	1470	7.5
Ferric	0	6.43	39.9	3.86	..	..	..	..	..	6.6
acetate	17	5.64	48.0	2.93	12.3	20.3	24.1	183	760	7.3
(basic)	30	4.76	51.2	2.32	28.0	28.3	40.0	435	1090	7.5
Ferric	0	6.35	40.3	3.78	..	..	..	..	..	7.0
citrate	17	5.15	48.2	2.67	18.9	19.6	29.0	220	758	7.4
	30	4.70	53.0	2.21	26.0	31.5	41.7	576	1380	7.4
Ferric	0	6.39	40.5	3.80	..	..	..	..	..	7.0
oxide	17	5.30	49.6	2.72	17.1	22.5	28.4	281	990	7.3
	30	4.42	61.7	2.13	30.8	27.7	43.0	635	1470	7.4
Iron	0	6.24	41.4	3.68	..	..	..	..	..	7.0
	17	5.36	50.0	2.68	14.1	20.8	26.8	281	1050	7.3
	30	4.79	51.4	2.32	23.2	24.2	36.6	636	1740	7.5
Ferric	0	5.95	41.2	3.50	..	..	..	..	..	7.1
hydroxide	17	5.14	49.4	2.60	13.6	19.9	25.7	335	1305	7.2
	30	4.41	51.5	2.14	25.8	25.0	38.9	659	1690	7.5
Control	0	6.28	40.4	3.74	..	..	..	..	..	7.1
	17	5.34	50.8	2.62	15.0	25.8	30.0	286	955	7.3
	30	4.54	50.3	2.26	27.7	24.8	39.5	640	1620	7.4

In fact, after a digestion period of 30 days not over 10 cc. of gas/gm. volatile matter added was obtained on any day, in contrast to the control which produced 56 cc. at the peak of gasification (19 days) and the $Fe(OH)_3$ treatment which produced 67 cc. at the peak of gasification (19 days).

Only 15 per cent of the gas produced by the control was produced by the $FeCl_3$ and $Fe_2(SO)_4$ treatment after a digestion period of 30 days. However, the solids reduction, volatile matter reduction, and ash increase of both of these mixtures are practically the same as the control.

Iron compounds may or may not produce an effect on the digestion of sewage solids. Ferric chloride and $Fe_2(SO_4)_3$ seem to have a decidedly retarding effect on gasification whereas $FeCl_2$, $FeSO_4$, iron citrate, iron

acetate, produce only a slight retardation of gasification, whereas Fe_2O_3 and iron have no effect.

Discussion

The retardation of gasification which consistently occurred upon the treatment of a ripe sludge–fresh solids mixture with certain iron compounds may be caused by a number of factors, two of which the author has determined. These two factors are:

1. The toxicity of the iron compounds.
2. The increased acidity resulting from the iron salt treatment.

Evidence pointing toward the toxicity factor is (*a*) the great reduction, in bacterial numbers due to $FeCl_3$ treatment, (*b*) the toxicity of $FeCl_3$ and the Cl^- ion, (*c*) the initial lag in the gas production curve from the experiment in which the reaction was adjusted with lime one hour after $FeCl_3$ treatment (Figure 4).

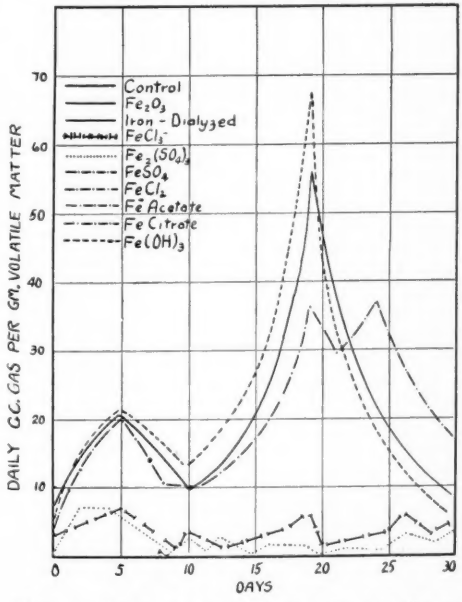

FIG. 9.—Daily gas production from ripe-sludge and fresh-solids mixtures treated with certain iron compounds.

It is not the opinion of the author that this toxicity is due to the $FeCl_3$, $Fe_2(SO_4)_3$ or other iron salt as such, but that upon the hydrolysis of the iron salt the anion plays the more important rôle. Starkey and Halvorson[1] have conclusively proved that $Fe(OH)_3$ passes into solution as the ferrous ion in a culture media undergoing anaerobic decomposition. Should the iron ion possess a toxic effect upon the gas-forming organisms, retardation of gasification would occur when $Fe(OH)_3$ treatment was made, which is contrary to the observed case.

That the acidity caused by the $FeCl_3$ treatment of a mixture of seeded sludge plays an important rôle in the degree of retardation of gasification was shown with some degree of success in Experiments I and II. The

lime reduces the retarding effect of $FeCl_3$, on account of its high buffering action in the sludge as well as its chemical combination with the $FeCl_3$ to form ferric hydroxide and $CaCl_2$.

Upon the addition of $FeCl_3$ to a mixture of seeded raw sludge a coagulation of the colloidal matter occurred. The coagulation can be attributed to the adsorption of the iron ion by the negatively charged colloidal particles. As a result of the adsorption of the iron, the anion will be free to diffuse into the solution. It is suggested that the chlorine ions may be detrimental to microörganisms before its charge is destroyed.

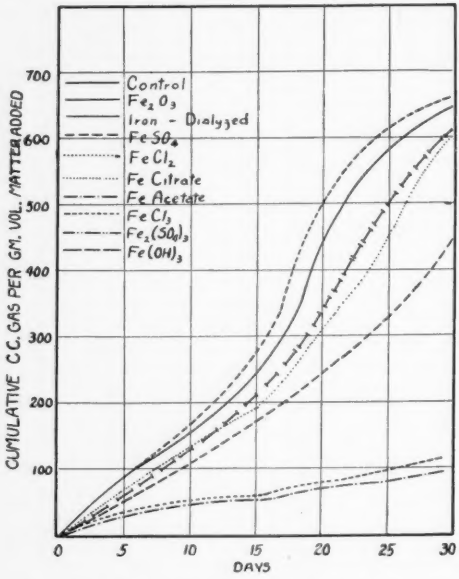

FIG. 10.—Gas production (cumulative) from ripe sludge–fresh solids mixtures treated with certain iron compounds.

Since the reduction of volatile matter is approximately the same with or without iron treatment, the liquefying organisms are apparently not affected to the same extent as the gas-forming organisms or else the intermediate products of decomposition, formed in the presence of iron compounds are more stable than those formed in the absence of iron compounds. There exists the possibilities (*a*) that the anion of $FeCl_3$ is more toxic to the gas-forming organisms, and (*b*) that the intermediate products are made more stable upon the physical and chemical combination with the iron salt.

It is known that iron salts combine either physically or chemically with organic complexes. Thus Creighton[3] found that ferric ions combined with protein but neither ferrous nor ferric ions combined with sucrose, glycerol, or tartaric acid. In considering such a chemical or physical combination the question of the relative stability of the resulting compounds and their resistance to microbial decomposition arises.

The process of leather tanning consists of the adsorption of the tannin, aluminum salt or iron salt by the leather. In this case the organic complexes do become more resistant to microbial decomposition. The possi-

bility exists that in sewage a similar effect is produced on some of the organic complexes or their intermediate products of decomposition.

It is more plausible, however, to assume that different groups of organisms have different reaction ranges than that the same concentration of salt is more toxic to one group than another. That is to say, the liquefying organisms may tolerate a lower pH value than the gas-forming organisms. Throughout this discussion it has been assumed that the organisms responsible for digestion are divided into two groups, those that liquefy the solid material and those that decompose further the intermediate liquid complexes producing end products such as gases and water. The experiments discussed in this paper as well as the theories of other investigators tend toward this division in the decomposition of organic matter.

In conclusion it must be borne in mind that although certain isolated facts are shown to cause the retardation of the decomposition of iron-treated sewage solids, other factors as yet not satisfactorily proved may play an equally important rôle.

Summary

The foregoing experiments have shown:

1. Gasification is not affected by the presence of less than 5 p. p. m. $FeCl_3$ solution, but gasification is progressively retarded by the presence of 5 to 20 p. p. m. $FeCl_3$ solution on the basis of 150 p. p. m. dry settleable solids.

2. Although this retardation results in the doubling or tripling of the digestion period, as much as 25 per cent more gas per gram volatile is ultimately obtained.

3. The neutralization of the acidity due to the hydrolysis of $FeCl_3$ which was accomplished by the addition of lime one hour after the $FeCl_3$ treatment, partially eliminated the retardation of gasification.

4. Quantities of iron chloride less than 10 p. p. m. $FeCl_3$ solution are not toxic, whereas $FeCl_3$ treatment greater than 10 p. p. m. caused a decided reduction of bacterial numbers. With the exception of fungi the reduction of microbial population was complete when 20 p. p. m. $FeCl_3$ treatment was administered.

5. Iron added as the element, oxide, or hydroxide had no appreciable effect on digestion.

6. Ferric acetate and citrate, ferrous chloride and sulphate caused a relatively slight retardation, but hardly comparable to the retardation of gasification produced by either ferric chloride or ferric sulphate.

7. In general the reduction of solids, volatile matter, and ash increase are the same regardless of the concentration of iron used.

8. The rate of oxygen consumption as well as the total quantity of

oxygen absorbed by fresh solids is independent of the quantity of iron compounds present.

9. Certain alkaline precipitants, particularly sodium aluminate, cause a stimulation of gasification.

References

[1] R. L. Starkey and H. O. Halvorson, "Studies on the Transformation of Iron in Nature," *Soil Sci.*, **24**, 381 (1927).

[2] E. J. Theriault, "The Oxygen Demand of Polluted Waters," *Bull.* **173**, U. S. Public Health Service (1927).

[3] H. J. M. Creighton, "The Behavior of Iron Salts toward Certain Reagents in the Presence of Proteins and Other Organic Substances," *Jour. Soc. Chem. Indus.*, **21**, 1029 (1912).

Sludge Disposal at Wakefield. W. H. HOYLE, *The Surveyor*, **77**, 589, May 16, 1930.—A description is given of the sludge disposal at Agbrigg Sewage Works, Wakefield. The sewage, which is essentially domestic but with a high grease content, is screened and treated, after preliminary settlement, by the bioaeration process, settled and the effluent discharged. The whole of the sludge was originally treated on drying beds properly constructed as sludge filters. As a result of the development of filamentous growths in the activated sludge, which led to difficulties in drying, lagoons were laid out and the sludge pumped on to them. The lagooned sludge, however, became offensive. Experiments on sludge digestion were then started and finally a non-offensive sludge was produced. The lagoons were, therefore, converted into digestion tanks where the activated sludge is pumped on to digesting settling tank sludge and the digested sludge run on to the drying beds where it is left until dry, raked up, stored, pulverized and sold as a fertilizer. A table of analyses shows that the process has comparatively little effect on the nitrogen content of the sludge and eliminates practically all of the grease. The process is cheap and can easily be adopted where land and pumping facilities are available. In discussion, J. H. Edmondson referred to the collection of sludge gas and suggested that if the process outlined were applied to large works means would have to be adopted to keep the sludge pH constant and to stir the sludge. Temperature was also important. Abst. No. **1060**, *British Summary of Current Literature, Water Pollution Research*, Vol. **III**, 9, Sept., 1930.

Notes on the Determination of Biochemical Oxygen Demand*

BY WILLIAM D. HATFIELD** AND KENNETH H. MORKERT***

One of the chief purposes of sewage purification is the removal of both the suspended and dissolved-oxygen-demanding materials, so that the dissolved oxygen in the stream receiving the purified effluent will not be materially lowered. The importance of the determination of the biochemical oxygen demand of sewage and effluents is recognized by all sanitary engineers and chemists.

The technic of this method as described in *Public Health Bull.* **132** and **173** and in *Standard Methods of Water Analysis—A. P. H. A.* is not difficult, but until mastered in a routine way is tedious to the worker not accustomed to it. Also the number of bottles, syphons, pipettes, etc., seems prodigious to the uninitiated. Because of these requirements, there are a great many variations in technic and apparatus used throughout the country. Each laboratory usually has some little deviation all its own, and in many cases these deviations have not been sufficiently checked against the standard method to afford a knowledge of the errors introduced. This paper is written to call attention to some of the pitfalls which may be encountered. Some of these conditions are not new but will bear restatement; others are conditions met with at the laboratories of the Decatur Sewage Plant.

Accuracy of the Dilution Method.—The accuracy of the dilution method is admirably discussed by Theriault in *Pub. Health Bull.* **173,** "The Oxygen Demand of Polluted Waters," from which the following quotations are taken. "Now including the error due to sampling and including all the observations, the percentage error at 20° C. is 7.2 per cent, corresponding to an average deviation from the mean of 4.1 per cent. These data are on undiluted river samples. From a series of observations on tannery wastes the percentage deviation for the tannery waste results was 7.5 per cent (corresponding to an average deviation of 4.2 per cent). Similarly, for the straw-board waste results the percentage error became 5.2 per cent (corresponding to an average deviation of about 3 per cent)." These results were obtained on the wastes diluted from 5 to 1000 times and Theriault concludes that "dilution is without appreciable effect on the precision attainable in the oxygen demand studies."

Of course such precision is obtainable only (*a*) when the temperature of the incubator is relatively constant, (*b*) when the dilution water is of high purity and its oxygen demand is suitably reduced by prolonged storage,

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(*c*) when the glass bottles are carefully washed with chromic acid cleaning solution, and (*d*) when careful attention is paid to the sampling, the measuring technic, and thorough mixing of the diluted sample.

At Decatur the principal sources of error have been found to be (1) in the proper cleansing of the incubation bottles, (2) in unstable dilution waters, (3) in the kind of dilution water, and (4) in the attempt to use cheaper glass bottles with rubber-stoppered water seals in place of the regular glass-stoppered bottles.

Cleansing of Dilution Bottles.—Although cleansing of the incubation bottles sounds quite simple the authors have found this to be a source of constant difficulty and variation due to the variable mentality of the wash boys. For example, a period of bad check results was stopped when a very conscientious wash boy was found, first, carefully washing the inside of the bottles with chromic acid and, secondly, carefully washing the outside of the bottles with soap suds to remove the red pencil marks. A reversal of this process stopped the trouble by eliminating the possibility of soapy water entering the inside of the bottles and not being thoroughly rinsed out. At present the outside is washed first and then cleaning solution added, shaken and allowed to set overnight. In the morning the bottles are thoroughly rinsed in hot water and distilled water and drained.

Dilution Waters.—In general a dilution water which shows a 5-day oxygen demand of from 0 to 0.4 p. p. m. in the blank sample is considered to be satisfactory but as pointed out by Theriault filtered and chlorinated tap waters may show this satisfactory drop in the blank samples and still have a considerable demand when inoculated with the sewage or waste in the diluted sample. Therefore the criterion for a good water is to get good check results on different dilutions of the same sample. Further, Mohlman[1] has shown that low results are obtained by the use of distilled water, and recommends a synthetic water containing 500 p. p. m. of sodium bicarbonate. Greenfield and Elder[2] have worked with various concentrations of other salts and indicate an advantage in the presence of calcium and magnesium ions. Further, distilled water is toxic to the normal flora of water and sewage, and the Committee on Standard Methods of Water Analysis of the A. P. H. A. specifically states[3] "that under no conditions should distilled water be used for dilution" in bacteriological analysis.

For four years the dilution water used in the Decatur Sanitary District laboratories was the plant tap water. The source of this water was a shallow well in a gravel pit near the plant. This water was stored in 5-gallon carboys for about a month after which time it usually showed a 5-day oxygen demand of from 0.2 to 0.4 p. p. m. at 20° C. Using this water and correcting for the 5-day demand of the blank in the usual way, satisfactory checks of 5 per cent on varying dilutions were obtained. An analysis of the aerated and stored tap water in the summer of 1926 is given in Table I.

TABLE I

COMPOSITION OF AERATED TAP WATER

Positive Ions	P. p. m.	Negative Ions	P. p. m.
Calcium (Ca)	114	Carbonate (CO_3)	178
Magnesium (Mg)	57	Bicarbonate (HCO_3)	0
Sodium and Potassium (Na and K)	12	Sulfate (SO_4)	112
Iron (Fe)	0	Chloride (Cl)	41
Ammonium (NH_4)	0.01	Nitrate (NO_3)	15
pH	8.7		

In 1927 a new gravel pit was opened in the same water-bearing gravel formation some 600 feet away from our well. This pit was equipped with a sand washing device which discharged the wash water from the pit into a nearby creek. During August, 1928, the water level was lowered to such an extent that both the well and the pit ran short of water. At this time the sand washing machine was changed to discharge this wash water back into the pit to conserve the water supply both for the well and the pit.

The dirty water from the washing of the sand never reached the well, but soluble materials washed from the sand almost immediately permeated the ground and gave the tap water a volatile-acidic and oxygen-demanding property which spoiled it for B. O. D. diluting water and also for distilling since the contaminating substance was volatile and actually concentrated in the distillate. The distilled water could not be used to dilute the samples for permanganate oxygen consumed because of the high blank. This contaminated tap water on standing 30 days seemed to give blanks which showed it to be a stabilized water, but which gave the typical increasing B. O. D. values with increasing dilutions that could be corrected by the method proposed by Theriault in *Pub. Health Bull.* No. **173,** pp. 41–42. This proved that the well water contained organic compounds which were not oxidized by prolonged storage, but which were oxidized when diluted with sewage or effluent samples. The depletion in the blank dilution water on incubation did not indicate the oxygen demand of the dilution water in the inoculated samples and thus gave B. O. D.'s often 100 per cent higher than the corrected values showed. A typical set of these results is given in Table II.

TABLE II

DATA SHOWING ONE EFFECT OF POOR DILUTION WATER

Five-day oxygen demand of dilution water	0.4 p. p. m.		
Concentration of sewage, per cent dilution	0.5	1.0	1.5
Observed depletion corrected for blank, cc.	2.47	4.33	6.0
Concentration factor	200	100	66.6
B. O. D. as calculated from above in p. p. m.	495	440	400
B. O. D. corrected after Theriault[4]	352	370	355
Deviation from mean in p. p. m.	−7	11	−4

This difficulty was partially overcome by inoculating the carboys of well water with settled sewage before the prolonged storage. However, this inoculated water often developed green algae growths and had to be discarded. Occasional erratic results were attributed to these growths.

Another fault with the shallow well water is that the salt concentration varies with the wet and dry seasons, thereby giving higher B. O. D.'s in dry seasons and lower B. O. D.'s in wet seasons.

An attempt was made to use the city tap water which is the natural stream water softened by lime, filtered and chlorinated. This water proved absolutely useless as a dilution water, showing no drop in the dissolved oxygen of the blank after the five-day incubation but a considerable drop (average of 0.9 p. p. m.) when inoculated with sewage samples. With a dilution factor of usually 100 it made the raw sewages 90 p. p. m. too high.

Bicarbonate-Distilled Dilution Water.—These variable factors in the well-water supply and the other erratic results led to the use of 500 p. p. m. sodium bicarbonate-distilled water. Good distilled water was first aerated, then the 500 p. p. m. sodium bicarbonate added and 30 days storage allowed. This water gives consistent results but results that are intermediate between those obtained with distilled water and tap water. In Table III are shown the results obtained with two samples of settled sewage using distilled water, bicarbonate-distilled water and inoculated well water for diluting waters.

TABLE III

COMPARISON OF DISTILLED, BICARBONATE, AND INOCULATED WELL WATER

	P. p. m. B. O. D.		
	Distilled Water	Bicarbonate Water	Inoculated Well Water
Settled Sewage Dec. 16, 1929		170	235
Settled Sewage March 5, 1930			
1% dilution	62	91	142
2% dilution	64	105	131
3% dilution	63	103	120
Average	63	99	131

These results are quite typical of many similar results obtained, showing that distilled water gives results on Decatur sewage between 30 to 40 per cent lower than the bicarbonate-distilled water, and, further, that the inoculated well water gives results 30 to 40 per cent higher than the bicarbonate-distilled water.

These data point out more strongly than did those of Greenfield, Elder and McMurray[2] the crying need for a standard dilution water containing the ions common to natural waters, *i. e.*, calcium, magnesium, sodium, potassium, bicarbonate, sulphate and chloride. Naturally a dilution water cannot be made which will correspond to the ionic content or concentration

of each river in the United States, and also an average concentration of the Mississippi basin would be different from that of the rivers on the east or west coasts. But leaving out of consideration the very soft waters on the east coast and the northwest coast, an average dilution water might be found satisfactory. From the analyses of the river-water supplies given in *Water Supply Paper* **496**, "Industrial Utility of Public Water Supplies in the United States," particularly those for the Mississippi, Ohio, Illinois, Missouri and Arkansas Rivers and the Great Lakes the following near-average ionic concentrations are suggested:

Positive Ions	P. p. m.	0.001 *N* Equivalents	Negative Ions	P. p. m.	0.001 *N* Equivalents
Calcium	40	2	Bicarbonate	122	2
Magnesium	12	1	Sulfate	48	1
Sodium (Potassium)	12	0.5	Chlorine	18	0.5

Such a water could be made by dissolving approximately

NaCl	58.5 grams per liter
$MgSO_4$	60.2 grams per liter
$CaCO_3$	103.0 grams per liter

The calcium carbonate would have to be converted to bicarbonate with CO_2 gas until the water had a normal pH of from 7.0 to 7.5. A study of such a synthetic water and the effect of varying the ionic concentrations 50 to 100 per cent might prove that it does satisfactorily represent the rivers in the Mississippi basin. The author hesitates to start such a study with his limited facilities and trusts that some one else, who has larger facilities, will become interested.

Quality of Distilled Water Used.—In 1929 the bicarbonate-distilled dilution water began to show a toxic effect, *e. g.*, lower results on higher dilutions. It was found that the head in our Barnstead Still had become loosened from the steam chamber and was allowing some of the burned Imhoff-tank gas to enter the condenser with the steam and thereby pollute the final distilled water. This toxic substance caused a lag in high dilutions but was gradually neutralized as the concentration of sewage in the dilutions was increased.

Rubber-Stoppered Water Seals.—The use of rubber-stoppered water seals is mentioned only because of its rather widespread use in certain localities. It is, of course, not standard procedure, but has appealed to some chemists because of the inexpensive bottle and the elimination of the water-seal rubber collar. It has been thought that the rubber stopper did not have an appreciable oxygen demand and that if there were a slight demand this would be corrected for in the depletion in the blank sample, which was also incubated with the rubber-stopper seal. However, it is shown below that the blank water does not support the oxidizing flora

necessary to oxidize the rubber in proportion to that obtained in the diluted sewage samples.

A study of the different types of bottles was made to see if the cheaper bottles could be substituted at Decatur. The results are shown in Table IV. In column one are the data using standard 250 cc. glass-stoppered bottles. In column two are the data on the same size bottles equipped with No. 0 rubber stoppers carrying a two-inch capillary tube. In column three are the data on a 142 cc. bottle (used in some places) carrying a No. 3 rubber stopper and capillary tube. These data show that the No. 0 rubber stopper introduces a sizable increase in the B. O. D. even though each set was calculated from its corresponding 5-day blank, and, further, that the larger No. 3 rubber stopper in the smaller bottle introduced a very large error. The data in Table IV were obtained with stabilized sodium bicarbonate dilution water.

TABLE IV

COMPARISON OF THREE TYPES OF DILUTION BOTTLES

	P. p. m. Biochemical Oxygen Demand. 5 Day		
	(1) Glass Stoppered Bottles 245 cc.	(2) No. 0 Rubber Stoppered Bottles 250 cc.	(3) No. 3 Rubber Stoppered Bottles 142 cc.
Dec. 17, 1929			
Settled sewage effluent	145	165	240
Dec. 26, 1929			
Crude sewage	56	68	97
Settled sewage effluent	39	67	(59)?
Pre-aeration effluent	33	56	110
Sprinkling filter effluent	18	32	47

Bicarbonate-distilled water used as dilution water: pH 8.6, alkalinity to M. O. 300 p. p. m.

A further study was made to show that the error introduced is proportional to the area of rubber exposed. Discs about 2–3 mm. thick were cut from No. 0 rubber stoppers and introduced into a series of bottles of blank dilution water and into 2 per cent Imhoff effluent dilutions, giving exposures of from 0 to 13 sq. cm. of rubber surface. The data are given in Table V and show that the drop in the blank dilution water samples was equivalent to about 7 p. p. m. B. O. D. per sq. cm. of rubber exposed while the actual error introduced in the 2 per cent dilutions (if calculated on the true blank) was between 16 and 19 p. p. m. per square centimeter. This shows conclusively that the rubber has a larger demand in the sewage dilutions than it has in the uninoculated blank dilution water bottle.

Measurement of Sewage Directly into Bottles.—Where not less than one per cent dilutions are made, equally good check results have been obtained by measuring samples directly into calibrated glass-stoppered

250 cc. bottles which had just been filled half to three-quarters full of dilution water. After the sewage or effluent is added to the partially filled bottle it is filled just into the neck and the stopper inserted so that only a small amount is forced out. If desired the bottle can then be shaken thoroughly and the rubber tube collar filled with dilution water for a seal. At Decatur all the bottles and stoppers have been numbered so that each bottle is always used with its proper stopper. The bottles were calibrated for their volume, when stoppered, by weighing them empty and full of distilled water at 20° C. The calculated volume is then scratched on the bottle and it is ready for use.

This calibration takes a little time at the start but amply repays for itself

TABLE V

OXYGEN DEMAND OF RUBBER STOPPERS

	Glass-Stoppered 250 Cc. Bottles				No. 0 Rubber-Stoppered Bottles			
No. of rubber discs per bottle	0	1	2	3	0	1	2	3
Sq. cm. of rubber surface	0	3.3	8.4	11.85	1.1	4.4	9.5	12.95
Cc. drop in blank water due to rubber	0	0.45	0.85	1.55	0.25	0.6	0.9	2.0
Cc. drop per sq. cm. rubber	0	0.14	0.10	0.13	0.22	0.14	0.10	0.15
Calculated error in a 2% dilution per sq. cm. rubber in p. p. m.	0	7	5	6.5	11	7	5	7.5
P. p. m. B. O. D. in sewage dilutions (2%)	144	208	281	340	165	222	281	340
Error introduced in B. O. D. per sq. cm. rubber surface, in p. p. m.	0	19	16	16	19	18	15	16

The dilution water used was the usual bicarbonate-distilled water.

in accuracy and time saved in the daily dilution technic. After using this method for a few months the author is convinced that the error introduced by measuring out the smaller volume in this direct method is more than counterbalanced by errors due to uneven distribution or stirring of the diluted material in dilution flasks or cylinders before syphoning the diluted sample into the incubation bottles.

Conclusions.—The dilution method for determining oxygen demand is accurate to five per cent if (1) the incubation bottles are carefully cleansed with cleaning solution, rinsed thoroughly and dried, and (2) if the dilution water is not toxic to the normal bacterial flora and is well stabilized with regard to its own organic matter content.

Distilled water should not be used for dilution water because it is toxic and gives low results.

Sodium bicarbonate-distilled water (500 p. p. m.) is a much better dilution water, but in our tests it gave lower B. O. D.'s than natural waters.

A standard synthetic dilution water should be adopted that contains calcium, magnesium, sodium, bicarbonate, sulphate and chloride ions. The authors suggest for study a water containing

$Ca(HCO_3)_2$	0.002 normal
$MgSO_4$	0.001 normal
NaCl	0.0005 normal

which is a near-average of the main river waters in the Mississippi drainage area and is not greatly different from the water in the Great Lakes.

The softened and chlorinated city tap water gave very bad results.

Rubber-stoppered water seals should never be substituted for glass stoppers since the rubber has an oxygen demand which varies according to the liquor which is in contact with it, *i. e.*, a very little demand in the blank dilution water, a high demand in strong sewage and a lessened demand in the successive effluents throughout the treatment plant.

Direct measurement of samples into calibrated incubation bottles gave results comparable with the standard dilution technic as low as 1 per cent dilutions (dilutions below 1 per cent were not tried). This method greatly reduces the daily routine work and is justified if the bottles are calibrated as described in the text. All bottles must be calibrated as there is a considerable variation in their content.

[1] Mohlman, Edwards and Swope, "Technic and Significance of the Biochemical Oxygen Demand Determination," *Ind. Eng. Chem.*, **20**, 242–246 (1928).

[2] Greenfield, Elder and McMurray, "Further Studies on the Oxygen Demand Test," *Ind. Eng. Chem.*, **18**, 1276–1278 (1926).

[3] J. F., Norton, "Minutes of the Meeting of the Committee on Standard Methods of the Laboratory Section," *Am. J. Pub. Health*, **20**, 74–75 (1930).

[4] E. J. Theriault, "The Oxygen Demand of Polluted Waters," ***Pub. Health Bull.***, **173**, 41–42 (1927).

Activated Sludge Experiments at the Calumet Sewage Treatment Works[1]

BY F. W. MOHLMAN[2] AND C. E. WHEELER[3]

The use of the activated sludge process for complete treatment of sewage has increased rapidly during the past decade. Although trickling filters are still far from obsolete, certain points of superiority have been demonstrated for the activated sludge process under particular conditions such as an excellent effluent, freedom from odors and flies, small area required and flexibility. In certain situations, such as, for example, at Chicago the superiority of the activated sludge effluent as compared with the trickling filter effluent is an important factor in favor of the former process. Likewise, in other instances the low bacterial content of the activated sludge effluent may be decidedly in its favor.

On the other hand, the comparatively large operating costs of the activated sludge process have frequently turned the balance in favor of trickling filters. The activated sludge process is more sensitive than trickling filters and requires much more careful and scientific control. Reduction of the operating costs has been the stimulus for more investigation and research than any other phase of this process. Ever since the early years of the development of this process back in 1914 and 1915 it has been known that the oxygen requirement for biological consumption is only a fraction of the total amount of air used. The utilization of oxygen has usually been reported between five and ten per cent, with the remainder of the air used for stirring or circulation of the sewage and sludge. In an effort to separate the two requirements, namely, oxygen for biological purposes and the necessity of intimate admixture of sludge and sewage, many mechanical devices have been proposed for stirring or circulation, with absorption of oxygen from the atmosphere either at the surface of the sewage or on surfaces of drops or spray thrown into the air by violent mechanical action.

It has also been realized for quite some time that it might be possible to accelerate the activated sludge process and thus reduce the detention periods formerly considered necessary. American design has usually required detention periods between five and six hours while English plants have usually been designed with considerably more liberal allowance.

If it were possible to obtain satisfactory results with greatly decreased power consumption and size of plant, the total cost of activated sludge treatment, including interest and depreciation, would probably be lower

[1] *Presented at Third Annual Meeting, Central States Sewage Works Association, Springfield, Ill., June 11, 1930.*

[2] *Director of Laboratories.*

[3] *Engineer-in-Charge of Calumet Treatment Works, The Sanitary District of Chicago.*

than that of trickling filters. Likewise, the use of the activated sludge process could be greatly extended and considerable economy might be effected in the operation of existing plants. A review of the practical developments that have tended toward economies might be of interest as an introduction to the work we have done along these two lines at the Calumet Treatment Works.

Reduction of Power Requirements

In the earlier plants using diffused air the diffusion was accomplished through the ridge-and-furrow type of tank bottom. Although this scheme gave very thorough aeration and agitation, the motion of the liquid was not uniform and the air bubbles rose directly from the plates to the surface as rapidly as possible.

Spiral-Flow Aeration.—The introduction of the spiral-flow type of aeration, as exemplified on the largest scale at Indianapolis and the North Side Treatment Works, is considered by us to be a distinct improvement in efficiency of aeration. The uniform motion of the liquid makes it possible to keep the sludge in suspension with less air and in our opinion the time of contact of the air bubbles with the sewage is longer than in the ridge-and-furrow system, where the bubbles rise directly to the surface. Our studies indicate a decided economy in air requirements when the spiral-flow type of design is correctly interpreted. Its efficiency depends upon the proper placing of the diffuser plates, the proper rate of air through the plates, the tank dimensions, the use of baffles and other variable factors. If these factors are not considered properly all of the benefits of this improvement may not be realized.

Mechanical Aeration.—When research showed the possibility of obtaining the required oxygen by absorption from the atmosphere, mechanical processes were developed which were entirely independent of diffused air. A few of these have been developed to quite extensive use, particularly in England. Others have been studied experimentally and their use, at least for the present, abandoned. The mechanical devices of most interest and practical use are:

1. The Haworth paddle-wheel process, as exemplified at the Sheffield plant in England. The use of the Hartley inclined paddle wheel may be considered as a modification of Haworth's process. This process has not been developed in America, probably because of the very shallow tanks and therefore the large area required. The paddles induce a very violent splashing and agitation of the surface of the sewage, and maintain a velocity of several feet per second through the channels.

2. The Simplex type of mechanical aeration is used quite extensively in England and to some extent in America. It appears to be possible

to use the mechanism in tanks ten or twelve feet deep, thus reducing the area required for the plant as compared with the Haworth process, in which the tanks have not been deeper than from four to six feet. The Simplex turbine discharges the sewage and sludge into the air in drops or spray and the oxygen required must be absorbed during this procedure.

3. There have been other mechanical schemes which have been studied in experiment and testing stations and in some cases these schemes have reached installation in small plants. One of the earlier of these schemes was the Trent proposal, whereby the sludge was stirred in a circular tank by a revolving arm similar in principle to the Barker mill. Air was drawn into the sewage and sludge during circulation, accomplished by means of a centrifugal pump. This suggestion originated in California some twelve or thirteen years ago but it has practically been abandoned and lines of development have diverged from the principles suggested by this device.

4. The possibilities of circulation through a central well by means of turbines have been considered and studied at some length in testing stations. Most of the variations of this procedure have been investigated by C. Lee Peck. Several turbines supplied by him were used at the Corn Products Testing Station of The Sanitary District of Chicago and various attachments were used for beating air into the circulating liquor. Later a plant using Peck's turbines was installed at Hagerstown, Maryland, where it was found necessary to provide additional diffused air. Whether Peck's device can be made to accomplish the same results obtained with the Simplex apparatus remains to be demonstrated. Recently, a California inventor has developed the so-called "Watsco" circulator, which seems to be merely a modification of Peck's apparatus with introduction of air at the throat of the turbine through a number of pipes which extend to the surface.

5. A slightly different mechanical device has been tested out at the Des Plaines River Treatment Works known as the Tark aerator. This consists of a cut-flight conveyor operating on a horizontal shaft on one side of a rectangular tank, which is baffled nearly to the bottom. This device induces circulation and vigorous surface agitation and it succeeded in producing a satisfactory effluent. Several plants using a modified Tark aerator have been installed in the East. A European development similar to the Tark aerator has been proposed by Dr. Kessener in Holland. A revolving street-sweeper brush provided the surface aeration, and internal circulation was secured with paddles on a horizontal shaft. Recent information indicates that Dr. Kessener proposes to eliminate the internal paddles and to obtain both circulation and aeration by means of the brush.

As we sum up these main developments of mechanical treatment it

appears to be possible to eliminate diffused air and still to obtain an oxidized or even a nitrified effluent. It also appears that a longer period of contact is required in the absence of diffused air. Harris and other English investigators have come to this conclusion and in The Sanitary District of Chicago we have likewise found that mechanical devices are not such intensive oxidizing devices as the use of diffused air. We have investigated the Dorr-Peck process, the Peck turbines, the revolving buckets proposed by D'Olier, the Simplex aerator, the Tark aerator, and combinations of paddle wheels and diffused air. The purely mechanical processes which depend entirely on absorption of oxygen from the air are not likely to show possibilities of accelerated oxidation. The tendency is apparently in the other direction, toward slower oxidation. When the sewage is violently agitated and sprayed into the air the oxidizing action is more rapid than when the surface alone is exposed. The exposure of thin films of liquor with repeated circulation has been suggested in the so-called "Stream-Flow" process proposed by Jenks and Levine. More recently Jenks has suggested spiral circulation with a vortex action.

Such conflicting claims have been made with regard to the power requirements of these various mechanical schemes that it would require a very careful study to determine on a comparable basis what each might require. The rate of absorption of atmospheric oxygen limits any efforts toward economy in mechanical devices which depend solely on absorption of atmospheric oxygen as induced by mechanical circulation.

Mechanical Agitation Plus Diffused Air.—The advantages of combined mechanical agitation and diffused air long ago appealed to the senior author and led to the design of a tank comprising agitation by means of paddle wheels and introduction of diffused air. This device has been tested out at several of our testing stations. The earliest studies were made at the Corn Products Testing Station from 1923 to 1925. In the studies of the activated sludge process at the Corn Products Plant we used wooden tanks approximately 6 by 12 feet in plan and 12 feet deep. Tank No. 3 of a series was provided with a ridge-and-furrow bottom with filtros plates set in the furrows. Some of these plates were retained when the tank was remodeled, and a paddle wheel on a horizontal shaft was installed, with the shaft directly above the filtros plates. This tank was operated from April 30, 1923, to November 1, 1925. The amount of air used was very much less than was used in the spiral-flow type of tank, frequently averaging less than one-third of the amount used in the latter. It was mechanically unsatisfactory to drive the shaft by means of immersed sprocket wheels and consequently the shaft was extended through a stuffing-box at the end of the tank and the driving sprocket was attached to the end of the shaft. Excellent results were produced by operation of this tank but it was realized that the dimensions of the tank were

not the best for the most efficient use of the paddle wheel, for the depth of the tank was too great in proportion to the width.

The results of the Corn Products Testing Station were not utilized in the design of a plant for full-scale treatment of those wastes, since a process of "bottling up" the wastes inside the plant was developed, which has been described elsewhere.

Following the Corn Products tests another combined paddle-wheel diffused-air tank was installed at the Des Plaines Treatment Works in a tank 15 feet square and 15 feet deep. The results progressed far enough to indicate that the use of the submerged paddle wheel alone was insufficient and that diffused air would have to be supplied. In 1926, Dr. Imhoff reported the installation and preliminary operating results of a paddle-wheel diffused-air tank at Essen-Rellinghausen, near Essen, Germany. The construction of the Essen-Rellinghausen plant was begun in May, 1925. There are several articles which describe the results obtained with this tank. The amount of air is reported as from 0.08 to 0.14 cu. ft. per gallon and the overall power requirement as between 7 and 8 horse power per million gallons. Analyses of the sewage treated have been reported, with considerable divergence between the results. The sewage could be considered, however, to be fairly representative of an American sewage and not so concentrated as the average German sewage. The very low horsepower reported appeared to be very low in comparison with the much larger requirement reported from all other installations of the activated sludge process, but there was no reason to believe that it would be impossible to get down to such a low amount in view of the work of Dr. Buswell and others with reference to the minimum air requirements for biological purification.

A combination paddle-wheel diffused-air tank was installed at our Calumet Treatment Works in the winter of 1928–29. This plant was installed to determine, if possible, the advantages of the combined mechanical and diffused-air process in comparison with a long series of continuous records at the Calumet plant of the operation of a diffused-air plant. It was also considered desirable to study the arrangement and location of the air-diffuser plates. In our original Argo plant the plates were directly under the shaft; Dr. Imhoff set the plates along the outer edge of the tank in the Essen-Rellinghausen plant, so that the rising air bubbles were directly opposed to the downward motion of the paddles. In our Calumet experiments we first used this arrangement and later we set the plates almost directly under the shaft, as in our early Corn Products experiments, in order to compare the relative advantages of these two procedures. The results under both conditions are described below.

In addition to the Calumet tests a paddle-wheel diffused-air process has been studied at Salem, Ohio, under the direction of the Dorr Company.

Within the last month (June, 1930) experiments were inaugurated at the new Los Angeles Experiment Station under the direction of R. F. Goudey, in which a paddle-wheel diffused-air tank is to be investigated.

Reduction of Aeration Period

When we consider the period of days required for oxidation of sewage without the presence of activated sludge it seems quite remarkable that in the presence of activated sludge we can accomplish in from four to eight hours the complete oxidation and nitrification of concentrated sewage. On the other hand the rapid passage of sewage through a trickling filter suggests that a period of four to eight hours may be considerably longer than is absolutely necessary. If the activated sludge process can be accelerated so that the complete treatment may be accomplished by an aeration period of two or three hours, or less, a marked economy may be effected in original cost for tank capacity and in fixed charges applicable to operating costs. For this reason one of the main lines of study and experiment with the activated sludge process has been directed toward the possibilities of reducing the period of aeration.

One of the earlier suggestions which has been followed out in many cases is the adoption of a short period of aeration with a long period of reaeration of sludge. Because of the reduced volume of sludge, in some cases this procedure may result in an overall reduction in tank capacity. The value of such procedure is somewhat doubtful, however, and reaeration of sludge has not been adopted to any large extent in America. English experience does not indicate what value, if any, is to be derived from the use of reaeration of sludge. Our experience at the Des Plaines plant indicates that reaeration of sludge may be of benefit when industrial wastes, difficult to treat, are present in the sewage, but there seems to be no marked economy under average conditions. It is true that very little fundamental research has been directed toward the function and mechanism of sludge reaeration. We are greatly in need of a more scientific explanation of what takes place during reaeration of sludge.

O'Shaughnessy and Watson at Birmingham have been responsible for the development of the so-called "bio-flocculation" which consists of a very short period of aeration followed by reaeration of sludge. This process has never been claimed to be complete activated-sludge treatment and has only been used preliminary to trickling-filter treatment. It must be recognized, however, that this procedure does comprise a two-stage process and as such is a forerunner of more recent studies of multi-stage processes.

The desirability of studying the division of the activated sludge process into various steps was recognized by those early proponents of the process, Ardern and Lockett. In their first paper in 1914 they reported the

results of bottle experiments in which the aeration was divided into two stages. The results indicated that there might be some advantage in such a division. More recently Dr. Ardern studied a two-stage process at the Withington Works in a small galvanized iron aeration tank 24 ft. 6 in. long, 1 ft. 7 in. wide and 2 ft. 9 in. deep. Very small settling tanks were used with a capacity of 200 gallons. A study of the results indicates that it is difficult to draw any very definite or convincing conclusions from the results of these tests and Dr. Ardern was not impressed by any particular advantages of the two-stage process as he studied it on this small scale. Recently Drs. Imhoff and Sierp have been interested in experimental work on the division of the aeration process into two or more stages. In The Sanitary District of Chicago we have also considered this modification and plans were drawn some three years ago for a large-scale test at the Des Plaines Treatment Works but this plant was not installed. Last year (1929) a two-stage process was installed at the Calumet Treatment Works on a larger scale than any tests that have been made thus far. It is understood that two-state aeration processes are now being studied at Los Angeles, and that Dr. Imhoff has been experimenting on a larger scale.

There are theoretical reasons to indicate that division of the work to be accomplished in sewage oxidation might be of advantage. The desirability of preliminary removal of coarser suspended matter has already been recognized, as evidenced by the installation of sedimentation tanks preceding aeration tanks. It may further be desirable to remove most of the remaining suspended and colloidal matter before attempting to carry out the final biological oxidation. This desirability has been considered and discussed by Mr. O'Shaughnessy with regard to final treatment on trickling filters. English discussion has pointed to the fact that trickling filters are, in effect, an application of the principle of biological stage treatment, with certain work accomplished in the upper layers and work of a different nature in the lower layers. In the activated-sludge process, however, the entire mass of floc and organic matter present in the sludge is carried through to the final discharge of effluent, and the oxidizing action which normally takes place toward the end of the process must bear the burden of a large amount of organic matter present in the sludge and removed from the sewage during the first few hours or even minutes of aeration. It is known that the presence of large amounts of organic matter inhibits nitrification. It would therefore seem reasonable to attempt to accomplish the clarification in one stage and the oxidation in another stage. This desirability has been discussed by Parson and Wilson of Reading, England.

From a practical standpoint the use of several stages of aeration with intermediate separation of solids means that additional units must be

supplied for intermediate sedimentation. If, however, the process may be accelerated so that the aeration period will be shortened to two hours, or less, the expense of additional sedimentation may be justified. In order to obtain more information on a large scale of the advantages of two-stage treatment, experiments were undertaken at the Calumet Treatment Works in 1929. These tests have not progressed far enough to

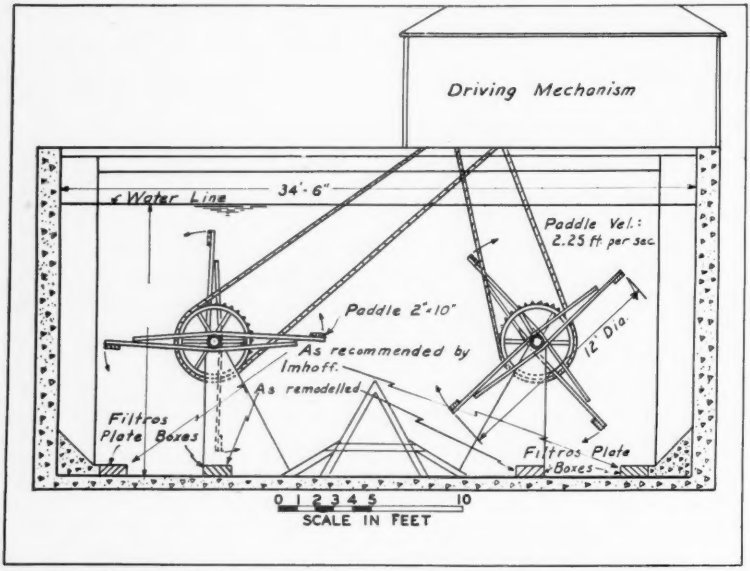


FIG. 1.—Paddle-Wheel Diffused-Air Activated-Sludge Unit, Calumet Treatment Works.

warrant any final conclusions, but a discussion of the results to date may be of interest.

Experiments at Calumet Treatment Works

I. Paddle-Wheel Tank.—Two of the Imhoff tank units at the Calumet Treatment Works were designed as activated sludge aeration tanks and have been in operation since 1923. Tank 25 was used for aeration of settled sewage and Tank 26 for aeration of raw sewage. Both units were followed by Dorr settling tanks. From 1.0 to 1.8 m. g. d. has been treated in each unit. Continuous operating records and analyses have been kept from the start of operation.

In 1928 Tank 25 was remodeled for use as a paddle-wheel diffused-air unit. The central baffle walls were removed, filtros plates were moved toward the outer walls, and two paddle wheels on long horizontal shafts

were installed, driven by a motor with reduction gears, sprockets and chain. A diagram of the cross-section of the tank is shown in Figure 1. The tank is 103 ft. long, 34 ft. wide and 14.5 ft. deep, with a net capacity of 360,000 gallons. The paddle wheels are 12 ft. in diameter with a 2 × 10 inch plank at the end of the radius arm. The paddles revolve in opposite directions at 3.6 r. p. m., giving a peripheral speed of 2.25 ft. per second.

During the first series of tests, from Feb. 20, 1929, to Jan. 10, 1930, the filtros plates were set directly under the paddles when the paddle arm was in a horizontal direction, that is, at the outermost swing of the revolving blades. Thus the rising current of air was directly opposed to the motion of the paddles, as in the Essen-Rellinghausen installation.

TABLE I

ANALYSES OF PADDLE-WHEEL EFFLUENT, TANK 25

PARTS PER MILLION

Month, 1929	Nitrogen as Org.	Ammonia	Nitrite	Nitrate	Dissolved Oxygen	5-Day B. O. D.	Suspended Solids Total	Volatile	Fixed	Meth. Blue Stability, Days
Feb.	4.2	5.3	0.1	0.2	9.3	63.0	80	47	33	3.5
March	3.7	3.9	0.2	1.5	9.1	38.0	68	41	27	6.0
April	2.7	3.0	0.5	1.5	7.4	13.0	58	29	29	9.5
May	2.5	3.7	0.0	0.4	3.5	8.3	29	16	13	7.8
June	2.2	3.5	0.2	0.4	4.3	8.1	35	20	15	8.3
July	1.5	0.6	1.2	0.7	4.4	6.0	18	10	8	9.8
Aug.	1.4	2.3	0.2	0.8	3.4	9.0	16	10	6	9.2
Sept.	1.8	4.1	0.3	0.4	3.5	10.9	12	8	4	9.4
Oct.	1.7	4.6	0.3	0.5	4.1	9.8	14	8	6	9.5
Nov.	1.5	4.9	0.1	0.4	3.6	7.7	18	11	7	9.4
Dec.	2.6	4.6	0.1	0.4	3.7	11.0	28	19	9	7.4

TABLE II

OPERATING RESULTS, PADDLE-WHEEL TANK 25

Month, 1929	Sewage Treated M. g. d.	Aeration Period, Hr.	Returned Sludge, Per Ct. of Sewage	Air Consumption (Free Air) Cu. Ft. per Gal.	Cu. Ft. per Plate per Min.	Suspended Solids in Aeration Tank P. p. m.	Settling Rate Dorr Tank Gal. per Sq. Ft. per 24 Hr.
Feb.	1.78	4.21	15.8	..	..	..	1571
March	1.67	4.67	19.1	0.27	1.71	..	1474
April	1.81	4.03	19.0	0.26	2.07	1982	1597
May	1.79	4.15	17.1	0.21	1.63	3016	1582
June	1.53	4.77	19.7	0.25	1.64	4683	1352
July	1.44	5.04	19.6	0.25	1.57	4456	1272
Aug.	1.44	5.05	19.4	0.23	1.43	4039	1270
Sept.	1.44	5.06	19.5	0.19	1.16	3511	1267
Oct.	1.44	5.05	18.8	0.21	1.34	2976	1270
Nov.	1.46	5.01	19.1	0.21	1.33	3262	1286
Dec.	1.46	5.01	18.8	0.21	1.31	2629	1286

Results, 1929, Paddle Wheel Tank, Air Opposing Paddles.—Monthly averages of daily analyses of the effluent are given in Table I and monthly average operating results in Table II.

The analyses in Table I indicate that an inferior effluent was produced at the start of operation and while activated sludge was being accumulated, but in April, 1929, and thereafter, a very satisfactory effluent was produced, containing considerable dissolved oxygen throughout the summer, with a 5-day oxygen demand varying between 6.0 and 13.0 p. p. m., methylene blue stabilities between 7.4 and 9.8 days, and suspended solids from 12 to 35 p. p. m. (excluding 58 p. p. m. in April). Although there was practically no nitrification the B. O. D. of the effluent was quite low.

Average results of analysis of the raw sewage for 1929 were, in parts per million: Organic nitrogen—6.3, NH_3 nitrogen—4.8, 5-day B. O. D.—72, suspended solids—123 total, 67 volatile and 56 fixed. The sewage is quite dilute, but it contains large volumes of inhibitory industrial wastes, which have been described elsewhere. The effect of these wastes was very detrimental in 1925 and 1926, and to some extent in 1927 and 1928, but by a process of control and uniform discharge the effect of the wastes was rendered less toxic in 1929.

The operating results for the paddle-wheel tank show that approximately 1.5 m. g. d. was treated in 1929, with an aeration period of 5.0 hours and air consumption of 0.20 to 0.25 cu. ft. per gallon.

TABLE III

ANALYSES OF ACTIVATED SLUDGE EFFLUENT, AIR ALONE, TANK 26, 1927
PARTS PER MILLION

Month, 1927	Nitrogen as				Dissolved Oxygen	5-Day B. O. D.	Suspended Solids			Meth. Blue Stability, Days
	Org.	Ammonia	Nitrite	Nitrate			Total	Volatile	Fixed	
Jan.	3.9	4.7	0.5	1.0	7.1	16.5	50	31	19	9.0
Feb.	3.3	4.3	0.8	1.0	9.1	18.6	42	25	17	9.6
March	2.1	3.2	1.1	1.8	8.6	18.2	38	22	16	9.8
April	2.1	0.8	0.6	3.5	8.8	13.8	46	24	22	9.9
May	1.8	0.5	0.1	4.1	7.4	9.9	45	24	21	9.9
June	1.2	0.7	0.0	3.6	7.5	5.9	25	15	10	10
July	1.3	0.7	0.0	3.1	6.9	6.1	25	14	11	10
Aug.	1.1	0.6	0.0	3.7	7.1	4.9	24	13	11	10
Sept.	1.5	0.6	0.0	4.0	6.5	6.0	36	20	16	9.9
Oct.	1.3	0.6	0.0	4.5	7.9	5.6	31	18	13	9.9
Nov.	1.6	0.5	0.0	4.2	8.6	6.6	29	17	12	10
Dec.	1.3	0.6	0.1	4.3	10.2	7.2	29	16	13	10
Av.	1.9	1.5	0.3	3.2	8.0	9.9	35	20	15	9.8

Results, 1927, Air Alone.—The other activated sludge tank at the Calumet Treatment Works, Tank 26, was used for pre-aeration and two-stage experiments in 1928 and 1929, consequently a direct comparison of results of Tank 25 with a similar tank, in which diffused air alone was used, cannot be made. In 1927, however, Tank 26 was operated to produce a completely treated effluent with a large amount of air and a liberal aeration period. The average operating results for Tank 26 in 1927 show

an air rate of 1.71 cu. ft. per gallon and 5.86 hours aeration. The quality of the effluent month by month is shown in Table III.

The raw sewage in 1927 averaged 121 p. p. m. suspended solids and 72 p. p. m. 5-day B. O. D., thus being quite similar to the composition in 1929.

The results in Table III show that even with the very large amounts of air used in 1927 the quality of the effluent produced was very little better than that of the paddle-wheel effluent in 1929. In 1927 a larger amount of nitrate was produced, but the B. O. D. and suspended solids in the

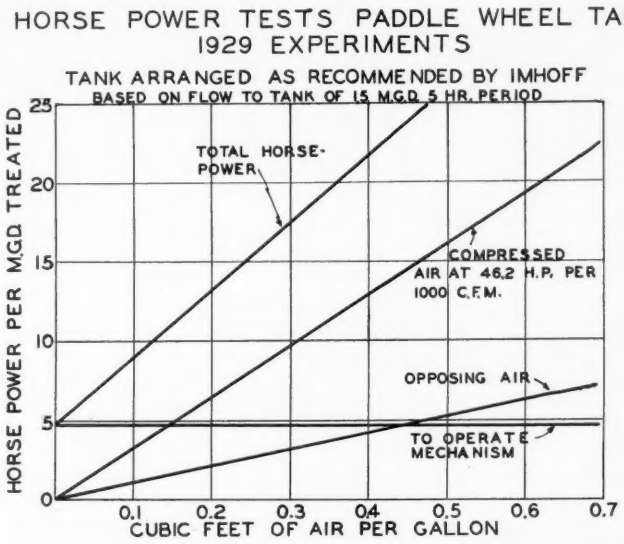


FIG. 2.—Horsepower Requirements, Current of Air Opposing Motion of Paddles.

effluents were about the same in 1927 and 1929. It must be recognized, however, that in 1927 the effect of toxic wastes was still quite appreciable, requiring the use of an excessive amount of air. Our best judgment indicates that it would require 0.80 cu. ft. of air per gallon, with air alone, and a 5-hour aeration period to produce an effluent comparable with that produced in 1929 by the paddle-wheel plus air, with 0.20 cu. ft. per gallon and a 5-hour period.

Power Requirements, 1929.—Careful measurements of power requirements of the paddle-wheel mechanism were made in 1929. The results were checked several times and a recording wattmeter was installed in 1930 on the motor which operated the driving chain for the paddle-wheels. The power required for mechanism and air is shown in Figure 2. The

power required for compression of air, 46.2 h. p. per 1000 cu. ft. per minute, was taken from the operating results of the North Side Treatment Works, where large, efficient units are in use. The combined or total horsepower is shown in the upper curve in Figure 2, based on treatment of 1.5 m. g. d., which gives a 5-hour detention period with 20 per cent returned sludge. The measured power requirements for the operation of the mechanism are, of course, 1.5 times the values shown in the curves.

It is quite apparent from Figure 2 that the opposition of the air bubbles to the motion of the paddles results in increasing power consumption for rotation of the paddles as the air rate increases. With no air the paddles required 4.7 h. p. per m. g. d. but this was increased by 1 h. p. (approximately) for each increase of 0.1 cu. ft. of air per gallon. At 0.20 cu. ft. per gallon, therefore, the paddles required 6.7 h. p. and the air 6.4, giving a total of 13.1 h. p. per million gallons.

With air alone at 0.8 cu. ft. per gallon, and a 5-hour period, the total requirement would be 26 h. p. per million gallons.

Disadvantages of Opposing Air to Motion of Paddles.—Observations of the surface of Tank 25 in 1929 indicated that the rising air bubbles at the sides of the tank almost completely nullified the uniform circulatory motion induced by the paddle wheels alone.

Circulation similar to the spiral flow motion was induced by the paddle wheels but when the air was started a rather disordered distribution of air bubbles was noted. Dr. Imhoff has emphasized the necessity for opposing the motion of the paddles in order to retain the air bubbles in the liquor for a longer time, but our observations led us to wonder whether or not the neutralization of the spiral or circulatory motion of the liquor might not be a greater detriment than any benefit that might be obtained from a presumably longer contact between liquor and bubbles. In order to study this question we remodeled the tank by moving the plates toward the center of the tank, under the shaft, as in the original tests at Argo in 1923. The new location of the plates is shown in Figure 1, with a single row slightly off-center with regard to the shaft. Tests with this remodeled tank were started March 9, 1930.

Results, 1930, Paddle-Wheel Tank, Air Aiding Paddles.—The time has been too short to date to accumulate sufficient data to warrant any definite conclusions concerning the average quality of effluent from the remodeled Tank 25. The month of March and part of April were spent in accumulating sludge. During April, however, results were practically as good as in April, 1929, even though the amount of air this year was only 0.16 cu. ft. per gallon, as compared with 0.26 cu. ft. per gallon last year. In May, 1930, the amount of air that could be passed through the plates was even less than in April, until the plates were partially de-clogged by higher pressure air applied on May 22, 1929.

There has been considerable difficulty in getting sufficient air through the old, badly clogged plates used for air diffusion. The air used in 1930 has been much less than in 1929. As shown in Table II, the rate for March, 1929, was 0.27 cu. ft. per gallon, April 0.26 cu. ft., and May 0.21

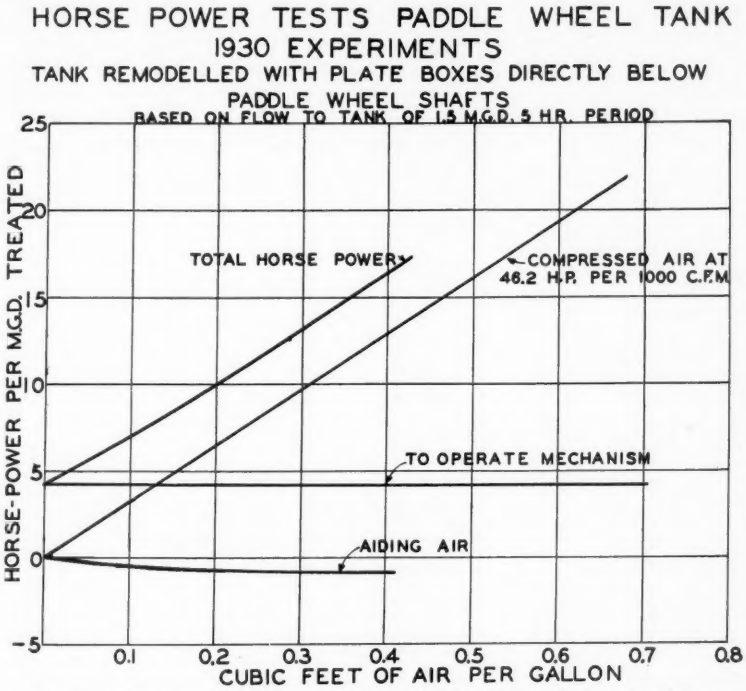


FIG. 3.—Horsepower Requirements, Current of Air Aiding Motion of Paddles.

cu. ft., whereas in 1930 the rate for March was 0.14 cu. ft., April 0.16 cu. ft., and May 0.18 cu. ft. per gallon.

Note. In June the filtros plates were replaced by new ones. The results in August, 1930, after accumulation of sludge, were quite similar to those in August, 1929. The air consumption is now being held as closely as possible to that used in the same month of 1929, so that results are comparable.

Notwithstanding the interruptions that have been encountered in operation of this tank since March, 1930, due to replacement of plates, the indications are that an effluent equal to that obtained last year will be produced as soon as uninterrupted operation can be maintained with 0.20 cu. ft. of air per gallon.

Power Requirements, 1930.—The power requirements with the plates under the shaft are shown in Figure 3. New sprocket wheels were installed,

which resulted in reducing the horsepower for the paddles alone, without air, from the 4.67 h. p. per million gallons required in 1929 to 4.27 h. p. per m. g. in 1930.

This reduction of power is small, however, in comparison with the remarkable reduction effected in the power required to operate the paddles in conjunction with diffused air. In place of an increasing power load for operating the paddles as the air rate is increased, the power actually

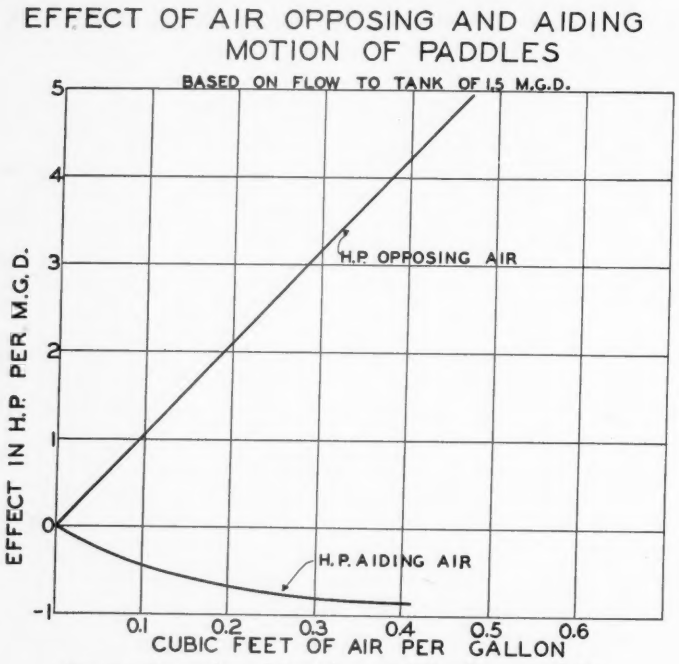


FIG. 4.—Comparison of Opposing and Aiding Currents of Air.

decreases slightly. In other words, the diffused air now aids the paddles instead of opposing them. The differences are shown in Figure 4, with an enlarged vertical scale indicating horsepower.

The overall horsepower under present conditions is shown by the top line in Figure 3. For example, at 0.20 cu. ft. per gallon, the paddles require $4.3 - 0.6 = 3.7$ h. p. and the air 6.4, giving a total of 10.1 h. p. per million gallons. This may be compared directly with the total of 13.2 h. p. required with the plates placed at the sides, opposing the motion of the paddles.

The appearance of the surface of the aerated liquor now is different

than formerly. The uniform circulatory motion induced by the paddle wheels is not broken up and neutralized when the air is turned on, but, as would be expected from a study of the power records, the air aids the circulatory motion of the liquor. Notwithstanding this induced uniform velocity, it does not appear that the air bubbles escape more rapidly, but, on the contrary, they may be seen to follow around with the streaming sewage and sludge, and to break at the surface all the way across the tank, from the center line to the walls. The appearance suggests that bubbles may even be carried down with the down-streaming currents, and it seems probable that the contact of air and sewage may be as intimate and sustained as before, if not more so. The indications so far are that results equal to those obtained last year will be obtained this year, but we feel that we can draw no final conclusions or comparisons until we have accumulated more operating data.

Discussion of Advantages and Disadvantages of Paddle-Wheel Diffused-Air Process.—While the saving in power by use of a combination of mechanical agitation and diffused air appears to be remarkable, there are other factors of importance that must be considered. We found both at Argo and Calumet that submerged sprocket-wheel drive was unsatisfactory, with frequent repairs needed due to breaking of chain pins. Recently a chain with alloy-steel pins was installed and we have had less trouble with this chain. For continuous operation, however, it may prove desirable to drive the shaft from outside the tank, with the shaft extending through a stuffing-box. If necessary to provide intermediate drive due to length of shaft it would be desirable to place the driving chain and sprocket in a dry well, built into the tank. Other types of driving mechanism might also prove desirable.

The operation of both air blowers and a large number of motors located outdoors over many tanks would require more labor than is necessary when diffused air alone is used. Likewise the saving in diffused plates, air lines, blowers and air-washing equipment might be less than the first cost of the auxiliary paddles and driving mechanism. Repairs and replacements would be more frequent with the paddle mechanism than with air alone.

In spite of these disadvantages there appears to be more promise in the future of the paddle-wheel, diffused-air process than in most of the other proposals that have been made and adopted for reduction of the power requirements of the activated-sludge process. The scheme is readily adaptable to large units. It is flexible in that the requirements for agitation and for oxygen may be supplied and adjusted separately, so that the air rate need not be excessive merely to maintain the required degree of agitation. The advantages of the combined processes will probably be more apparent with concentrated rather than with weak sewages.

The tests at Calumet indicate that from 10 to 15 horsepower per million gallons was sufficient. Dr. Imhoff claims a requirement of 7 to 8 horsepower for the combined scheme; the results at Salem, Ohio, also show a low requirement, according to our information around 15 to 20 horsepower per million gallons. The Salem sewage is considerably more concentrated than that at Calumet. Further substantiation of these low results should warrant careful studies of the possibilities of the combined process by all concerned with the development and further use of the activated-sludge process.

II. Two-Stage Process.—Tank 26 at the Calumet Treatment Works was remodeled in 1929 for large-scale experimental study of the two-

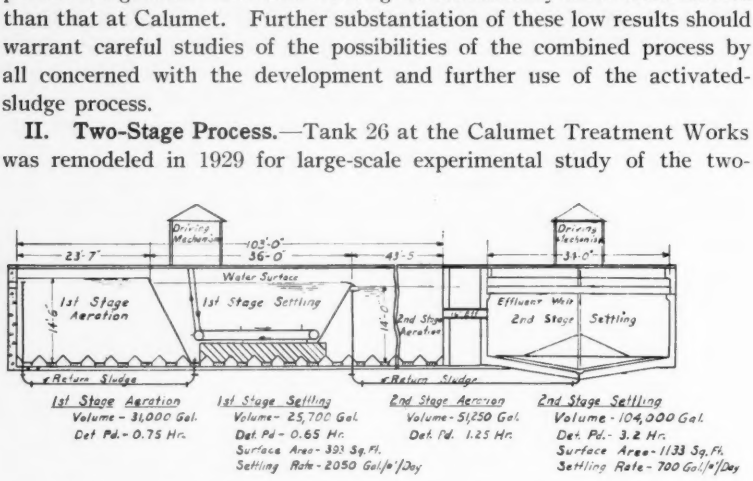


FIG. 5.—Two-Stage Activated-Sludge Process, Calumet Treatment Works.

stage activated-sludge process. Only one bay of the three bays comprising Tank 26 was used for this work.

The final Dorr tank was well adapted for settling of sludge from the second-stage aeration tank, but it was necessary to provide an additional settling tank for the first stage. This tank was provided by installing Link-Belt mechanism and scrapers in a section of the aeration tank between the first and second stages of aeration. A longitudinal section of the remodeled tank is shown diagrammatically in Figure 5. The tank was 11.1 ft. wide, 14.5 ft. deep and 103 ft. long. Dimensions and capacities of the unit are shown in Figure 5. The filtros plates were not changed from the original ridge-and-furrow installation. There are 60 plates in the first aeration tank and 92 in the second. All plates were originally connected to the same air line and meter, but in December, 1929, a separate Venturi meter was installed on the air lines to each aeration stage and since then the rate can be varied as desired. The settling rate for the primary settling tank has been considerably more rapid than is usually desirable for activated sludge, but this has not been considered to be a

disadvantage since it is neither necessary nor desirable to prevent a small amount of sludge from passing through to the second aeration tank.

The two-stage process was started Oct. 19, 1929. Analyses of the raw sewage treated and the settled effluents from the first and second stages are given in Table IV; operating records are given in Table V.

Analyses and Operating Results.—The average results of analyses of raw sewage and effluents shown in Table IV indicate that the final effluent has been quite satisfactory, with a comparatively low B. O. D. and a small amount of suspended solids. The highest B. O. D. and suspended solids in the final effluent occurred from January through April, the period of the year when results are usually poorest. (*Note.* During the summer lower values for B. O. D. and suspended solids were obtained for the final effluent, as shown in Table IV.) The results of analyses for both the effluents from the first and second stage show little nitrification, but notwithstanding this fact a low B. O. D. was obtained in the final effluent.

TABLE IV

ANALYSES OF SEWAGE AND EFFLUENTS, TWO-STAGE ACTIVATED-SLUDGE PROCESS
RESULTS IN PARTS PER MILLION

	Raw Sewage			Effluent, First Stage				Effluent, Second Stage				
Month, 1929–30	Org. + NH_3 N	5-Day B. O. D.	Susp. Solids	NO_2 + NO_3 N	Dissolved Oxygen	5-Day B. O. D.	Susp. Solids	Org. + NH_3 N	NO_2 + NO_3 N	Dissolved Oxygen	5-Day B. O. D.	Susp. Solids
Oct.	11.8	79	107	1.1	5.5	38	81	6.9	1.4	6.6	11.6	25
Nov.	13.0	79	132	0.9	2.3	22	52	6.9	0.7	7.6	7.3	17
Dec.	13.2	89	119	0.6	1.7	23	45	7.5	0.6	7.6	8.4	13
Jan.	10.5	71	106	1.4	5.9	25	43	6.8	1.5	9.8	13.8	29
Feb.	10.0	78	122	1.2	4.5	32	70	6.2	1.4	8.5	13.2	28
March	12.1	88	118	1.1	2.4	35.8	82	7.4	1.1	7.4	14.7	25
April	11.3	76	101	1.2	3.6	35.8	69	6.4	1.4	5.9	14.8	29
May	12.6	94	150	0.5	0.9	35	68	6.9	0.6	4.7	9.1	18
June	13.2	93	139	0.4	0.6	39	92	7.0	0.7	4.6	7.0	14
July	12.7	84	135	0.4	0.9	37	57	3.7	3.0	4.5	7.6	13
Aug.	11.6	71	124	0.3	0.9	22	52	1.9	4.3	4.1	6.0	12

According to the operating results shown in Table V approximately 800,000 gallons of sewage has been treated per day, with an aeration period of approximately 0.8 hour in the first stage and 1.3 hours in the second stage, making a total aeration period of 2.1 hours. There was no reaeration of sludge. This total aeration period for production of a completely treated effluent is very much shorter than we have obtained previously, although approximately the same period was used during the pre-aeration experiments in 1928 and 1929. The air requirements shown in Table V range from 0.5 to 0.9 cu. ft. per gallon, excluding the

first month. (*Note.* Approximately 0.5 cu. ft. per gallon was applied during the summer.)

Comparative Removals, First and Second Stage.—It is of interest to compare the work done by the two stages, as shown in Table VI. The removal of suspended solids in the first and second stage has varied considerably, although usually a larger amount of suspended matter has been removed in the first stage.

TABLE V

OPERATING RESULTS, TWO-STAGE PROCESS

Month, 1929–30	Sewage Treated M. G. D.	Aeration Period, Hr.	Returned Sludge, Per Ct. of Sewage	Air Consumption (Free Air) Cu. Ft. per Gal.	Air Consumption (Free Air) Cu. Ft. per Plate per Min.	Suspended Solids in Aeration Tank P. p. m.	Settling Rate Dorr Tank Gal. per Sq. Ft. per 24 Hr.	Stage
Oct.	0.795	0.79	19.7	1.11	4.0	..	2019	1
		1.30	19.7			3418	700	2
Nov.	0.745	0.83	20.1	0.93	3.2	3860	1895	1
		1.38	20.0			3740	655	2
Dec.	0.750	0.83	20.2	0.77	2.6	3314	1903	1
		1.37	19.8			4414	660	2
						(Down from Dec. 15–31)		
Jan.	0.760	0.82	19.8	0.58	5.1	2557	1910	1
		1.35	19.6	0.34	1.9	1965	668	2
Feb.	0.788	0.80	18.9	0.47	4.2	2377	2005	1
		1.31	19.0	0.27	1.6	3400	695	2
March	0.813	0.78	18.3	0.34	3.2	2526	2060	1
		1.28	18.3	0.22	1.4	2907	720	2
April	0.800	0.79	18.7	0.31	2.9	1967	2037	1
		1.29	18.7	0.21	1.2	2745	705	2
May	0.805	0.78	18.6	0.30	2.8	3979	2050	1
		1.29	18.3	0.20	1.2	3055	710	2
June	0.800	0.78	18.6	0.29	2.7	3902	2045	1
		1.29	18.2	0.20	1.2	2978	708	2
July	0.800	0.78	18.6	0.30	2.8	3390	2040	1
		1.29	18.4	0.21	1.2	3056	709	2
Aug.	0.820	0.76	18.3	0.30	2.8	3530	2090	1
		1.27	17.9	0.20	1.2	2949	724	2

The removal of B. O. D. in each stage is more consistent than the removal of suspended matter. The B. O. D. removal in the first stage has usually been 2 to 4 times as great as in the second stage. It is logical to expect more work to be accomplished in the first stage, in accordance with the studies that have been made of the relative rates of purification by the activated sludge process.

Although the purification may be greater in the first stage as indicated by the B. O. D. results, if the settling is inadequate and the sludge is in very poor condition it will pass through the first settling tank. This is what occurred in March. The sludge in the first stage became some-

what slimy and poorly flocculated, and it did not have the appearance of true activated sludge. This condition was greatly improved April 22 by return of 4600 gallons of sludge from the final settling tank to the first aeration tank. For several weeks following this transfer of sludge, the sludge in the first aeration stage was well flocculated and could be retained in the primary settling tank. Late in May the sludge in the first stage again became light and poorly flocculated and began to pass into the second aeration tank. Sludge has been returned occasionally from the second stage to the first in order to prevent deflocculation and dispersion of solids in the first aeration tank.

We have not been able to control accurately the exact amount of solids desired in the first and second stages but are attempting to carry the

TABLE VI

REMOVAL OF SUSPENDED SOLIDS AND B. O. D.—FIRST AND SECOND STAGES
PARTS PER MILLION

Month, 1929–30	Susp. Solids					B. O. D.				
	Raw	Eff. First Stage	Final Eff.	Removed 1st St.	Removed 2nd St.	Raw	Eff. First Stage	Final Eff.	Removed 1st St.	Removed 2nd St.
Oct.	107	81	25	26	56	79	38	12	41	26
Nov.	132	52	17	80	35	79	22	7	57	15
Dec.	119	45	13	74	32	89	23	8	66	15
Jan.	106	43	29	63	14	71	25	14	46	11
Feb.	122	70	28	52	42	78	32	13	46	19
March	118	82	25	30	57	88	36	15	52	21
Apr.	101	69	29	32	30	76	36	15	40	21
May	150	68	18	82	50	94	35	9	60	25
June	139	92	14	47	78	93	39	7	54	32
July	135	57	13	78	44	84	37	8	47	29
Aug.	124	52	12	72	40	71	22	6	49	16

larger concentration in the first stage, averaging approximately 4000 p. p. m., and 3000 p. p. m. or less in the second stage.

Discussion of Advantages and Disadvantages of Two-Stage Process.—Our experiments have not progressed far enough to warrant final conclusions with regard to the efficiency of the two-stage process as compared with the normal process of activated-sludge treatment. While we have obtained good results with a very short aeration period and comparatively low amount of air, we also obtained almost as good results last year in our pre-aeration experiments, in which a single stage of aeration was used plus reaeration of sludge. The two-stage process is very sensitive biologically and requires careful control, which we have not completely perfected as yet, although the sludge produced in the second stage from the Calumet sewage has generally been well flocculated, settleable sludge. It might be possible to retain sludge in the first stage, even with concentrated sewage, by returning sludge occasionally or even con-

tinuously from the final settling tank but there will probably be operating difficulty in preventing the sludge from passing through the primary settling tank. This difficulty has not been serious so far in the Calumet tests. The flexibility of the process commends it. The proper operating conditions will have to be found for various types of sewage, and consideration will have to be given in design for seasonal variation and peak flows, but our results indicate a possibility in this scheme for reduction of time required for aeration. Whether such reduction in size of aeration tanks will pay for the cost of additional settling tanks will have to be determined.

Acknowledgment

This work was carried out under the supervision of Langdon Pearse, Sanitary Engineer of the District. We wish to acknowledge the assistance of Ralph Bushee for design of the paddle-wheel tank and of J. Irwin Smith for the analytical data. The engineering work of the District is under the direction of Edward J. Kelly, Chief Engineer, and Philip Harrington, Principal Assistant Chief Engineer.

Status of Sewage Treatment in Germany.—A very interesting résumé of the present status of the activated sludge process was presented by Dr. F. Sierp, of the Ruhr District, at a meeting of various technical officials of German cities, held Sept. 3, 1930, at Leipzig. The paper has been printed by the Ruhr District, together with a paper by Dr. Imhoff on the function and value of sewage districts and another paper by Dr. Mahr on the utilization of the purifying power of streams as complementary to processes of sewage treatment. Other papers were presented, by Dr. Prüss, of the Emscher District, on recent progress in mechanical devices for sewage settling and sludge digestion, by Director Mieder, of Leipzig, on mechanically cleaned settling tanks, by Commissioner Langbein, of Berlin, on the advantages of preliminary activated sludge treatment for extension of the usefulness of the Berlin sewage farms, and by Director Maier, of Stuttgart, on the use of trickling filters in Germany. The meeting was presided over by Dr. Beninde, Director of the Berlin Institute. The papers and discussions were reviewed by Dr. Heilmann in *Gesundheits Ingenieur* for October 11, 1930. The growing interest in the activated sludge process is noteworthy. Dr. Prüss, however, stated that it should be recommended with caution for small cities. Dr. Imhoff stated that sewage farms and trickling filters will not be used in the future in Germany. Director Mieder discussed the mechanical sludge scraper used at Leipzig. Dr. Beninde urged further interchange and open discussion of the technical details of sewage disposal.

Sewage Works Operation

Observations on Scum in the Imhoff Tanks of the Ruhr District[1]

By Karl Imhoff[2]
Translated by Gordon M. Fair[3]

Among the sixty-four treatment works that are being operated at the present time by the Ruhr District there are twenty-seven Imhoff tank plants. Two of the latter, those of Langendreer and Witten, are about twenty-three years old and thus belong to the oldest installations of their type; five others were built before the war; the remaining twenty were constructed by the Ruhr District during the last six years.

The accompanying table presents the most important details of the 27 plants. It is evident that they are subjected to a wide range of operating conditions and that it is possible to draw conclusions of general applicability from the records of operating experiences gained at these plants.

Sewerage in the Ruhr District is generally complete for water-carried wastes, but there are still many house connections with privy vaults. In some communities the contents of pit privies are emptied into the collecting system. The Ruhr District permits these objectionable practices in order to protect its water courses against pollution by illicit discharges of fecal matter.

The industries of the communities served by Imhoff-tank plants are very diverse (Columns 3 and 4 of the accompanying table). Ten of the works treat purely domestic sewage. Twelve others include industrial wastes, but the resulting mixed wastes do not differ appreciably in character from domestic sewage. Only in five plants is the composition of the sewage and sludge changed markedly by the industries, namely, at Boele, Kettwig, Kupferdreh-Langenberg, Menden and Neheim.

An increase in the mineral content of the sewage by mining operations which changes completely the processes that take place in the numerous Imhoff tanks of the adjacent northerly coal-mining region is insignificant in the Ruhr District. Mine waters are included in only two plants and do not play a significant part. The temperature of the sewage, which is high and hence favorable to Imhoff-tank operation in the true coal-

[1] German Publication in *Technisches Gemeindeblatt*, **33**, 16, Aug. 29, 1930.

[2] *Chief Engineer, Ruhr District, Essen, Germany.*

[3] *Associate Professor of Sanitary Engineering, Harvard University, Cambridge, Massachusetts.*

mining region, is normal in the Ruhr District. The mean yearly temperature of the sewage generally lies between 10° and 15° C. (Column 7 of the accompanying table).

The detention periods of the sedimentation compartments (Column 6) lie generally between two and three hours. They are relatively high, because it is usually important to attain the complete sedimentation effect in order to reduce the load on the subsequent biological treatment works or on the Ruhr River which serves as the main water supply of the district. The sludge-digestion compartments are generally large because of the low sewage temperatures. They have capacities varying from 1.0 to 1.7 cu. ft. per capita of tributary population (Columns 8 and 9). Heated sludge-digestion tanks (combined with Imhoff tanks) are installed in four plants. Their performance has been excellent. In connection with the size of the digestion compartments it should be noted that eight works are provided with storm-water tanks, from which the sludge is pumped into the Imhoff tanks (Column 11). Eight works include biological treatment by contact aerators, trickling filters or activated-sludge tanks. The sludge produced in these treatment processes is also returned to the Imhoff tank (Column 12).

Gas collectors situated above porous-plate or wooden filters are installed in twenty plants (Column 10). As a rule the gas that is captured is not utilized; only in five works is it sold; in four works it is employed to heat the separate digestion tanks. At Iserlohn the gas is utilized in generating the power required by the activated-sludge units; likewise at Hattingen for the contact-aeration plant and for a sewage pumping station.

The performance of these Imhoff-tank plants must be considered separately with respect to sewage clarification and sludge digestion.

As regards clarification of sewage, we have found the sedimentation effect to be the same in Imhoff tanks as in the best settling units of different construction operated by the District, wherever the detention period is the same and the composition of the sewage is similar. In any case we have not encountered disturbance due to the structural connection of the settling compartments with the digestion compartments. Two-story tanks, because of the simplicity and reliability of performance associated with them, have a definite advantage over settling units equipped with sludge-removal mechanisms employing pumps or scrapers.

As regards sludge digestion, Imhoff tanks were, during almost twenty years, the only units in which well-digested sludge was produced in a short digesting period. Only since the introduction of artificial heating have equally good results been attained also in separate single-story digestion tanks.

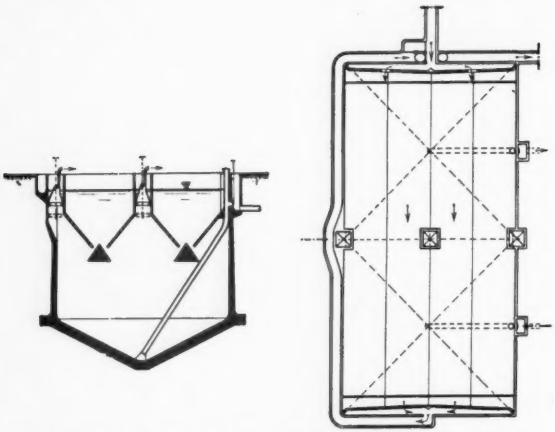
In all types of digestion compartments, single-storied or double-storied, acid fermentation may set in during the ripening, or breaking-in period,

IMHOFF TANKS IN THE RUHR DISTRICT

	(1)	Tributary Population (2)	Type of Industrial Wastes (3)	Industrial Wastes Proportion of Sewage Per cent (4)	Quantity of Sewage Gal. per Cap. Daily (5)	Dry Weather Detention Period (4-hour Average) Minutes (6)	Temperature Sewage, Yearly Average °C. (7)	Size of Sludge Digestion Chamber Cu. Ft. per Cap. (8)	Size of Separate Sludge Digestion Tanks (9)	Gas Covers and Gas Collectors (10)	Storm-Water Tanks (11)	Biological Treatment (12)
1	Arnsberg	5,000	.....	..	37	180	9.5	1.06	...	...	...	.....
2	Blankenstein-West	3,000	.....	..	26.4	150	11	1.76	...	Yes	Yes	.....
3	Boele	4,000	Iron works	80	190	120	...	1.94	...	Yes	...	.....
4	Bövinghausen	1,000	.....	..	26.4	120	11	1.37	...	...	...	.....
5	Dahlhausen-Süd	7,000	Machine shops	10	48.9	100	12	1.87	...	Yes	...	.....
6	Essen-Rellingh.-I	50,000	Mining	66	216	20	15	0.92	0.49	Yes	...	Activated sludge tanks
7	Essen-Bredeney	150	.....	..	26.4	120	16	1.13	...	...	...	.....
8	Gevelsberg	7,800	Iron works	10	39.6	120	10	2.46	...	Yes	...	.....
9	Hagen	93,000	Iron works	20	71.3	55	12	0.95	0.35	Yes	Yes	.....
10	Hattingen-Stadt	17,000	Textile mills Smelting, phenol	20	37	90	15	1.06	...	Yes	Yes	Contact aerators
11	Hattingen-Ost	2,000	.....	..	39.6	180	16	1.27	...	...	...	.....
12	Heiligenhaus	3,000	Hardware	5	31.7	100	...	1.98	...	Yes	Yes	.....
13	Holsterhausen-Hospital	400	Disinfection	..	106	150	...	3.17	...	Yes	...	Fish ponds
14	Iserlohn	19,000	Hardware	10	41.9	180	13.5	2.0	...	Yes	Yes	Contact aerators and activated sludge tanks
15	Kettwig	6,300	Wool washing	60	100	60	17	1.76	...	Yes	Yes	.....
16	Kupferdreh-Langenberg	20,000	Dyeing, wire works	60	72.6	80	12	0.63	0.63	Yes	Yes	.....
17	Langendreer	30,000	Wire works Mining	20	92.5	60	13	1.27	...	Yes	...	.....
18	Menden	12,500	Metal working	50	42.2	210	12	1.58	...	Yes	...	Contact aerators
19	Neheim	12,500	Metal working	50	46.2	95	11	1.41	...	Yes	...	.....
20	Neviges	5,000	Textile, hardware	10	31.7	240	10	2.11	...	Yes	...	Trickling filters
21	Steele	30,000	Mining	10	124	120	18	0.99	0.92	...	...	.....
22	Untergrüne	5,000	.....	..	99	120	...	1.34	...	Yes	...	.....
23	Velbert	20,000	Hardware	5	42.2	180	11	1.76	...	Yes	Yes	Contact aerators
24	Welper	5,000	.....	..	44.9	120	10	1.76	...	Yes	...	.....
25	Werne	3,000	.....	..	22.2	60	13	...	...	...	...	Contact aerators and activated sludge tanks for phenolic wastes of Mansfeld mine
26	Wetter	6,000	Iron works	10	48	150	12	1.41	...	Yes	...	.....
27	Witten I	22,000	.....	..	87.1	80	11	1.30	...	...	...	.....

as manifested by foaming and rising of sludge. This acid fermentation is overcome in the presence of adequate heat by natural means. Artificially this condition can be combated by seeding (mixing with old sludge of a good plant); liming is less reliable. Scum formation may take place quite regularly after the ripening period and without acid fermentation. Both occurrences, foaming and scum formation, may be objectionable in plant operation.

In the works of the coal-mining region these occurrences were not observed to any extent. This may be due to the peculiar conditions that are favorable to the operation of Imhoff tanks (*i. e.*, mineral content and



Ruhr District Design of Imhoff Tanks Equipped for Gas Collection.

high temperature). Since unfavorable observations of this kind have been reported, however, from other parts of Germany and from North America, it is of special interest to collect information on the performance of the twenty-seven installations of the Ruhr District which operate under widely varying conditions.

True foaming during the ripening period has been observed up to the present only in one plant, at Hagen. Foaming reappeared after the tanks were emptied by faulty operation and had to repass through the ripening period, and later again when the tanks were overloaded with sludge.

That foaming was not manifested during the ripening period in the remaining plants of the Ruhr District may be ascribed to the fact that it was possible to connect most of them to parts of an existing sewerage system in which old sludge from privy vaults permitted a rapid breaking-

in of the tanks by natural means. Furthermore, most new plants were artificially seeded by the addition of good sludge from other works.

Foaming may be brought about in Imhoff tanks also outside of the ripening period by overloading them to such an extent that the sludge level extends above the slots and thus shuts off the settling compartment from the sludge compartment for a protracted period of time. Foaming of individual tanks due to overloading may be prevented by careful operation. Care should be taken that the sludge level never reaches the slots.

Scum is not encountered at all in eighteen of the twenty-seven installations. In these eighteen plants the scum layer never becomes so deep that it interferes in any way with the tank operation. The attendant need not concern himself with it. In eight plants the scum layer is broken up or removed after shorter or longer intervals of time. Scum formation is generally greatest wherever the digestion compartment possesses the largest free surface, as at Arnsberg. The smallest scum layer is associated with those plants in which the sludge compartment is completely closed off from the atmosphere. For this reason gas collectors have been built into many small plants even though there is no possibility of utilizing the gas. (See accompanying figure.)

At Arnsberg and Steele the scum is caused to sink by weekly breaking-up and wetting. The old installation at Witten, which stands in need of structural repairs, requires this operation to be performed daily. A jet of water is used for wetting the scum. At Kupferdreh mechanical breaking-up of the scum is secured by blowing compressed air into it every three weeks. At Hattingen a jet of water is introduced, for the same purpose, through the sludge slots and is aided in its work by small stirrers situated beneath the gas domes. At Holsterhausen a simple stirring device is employed. The stirrer reaches below the gas collector and is revolved every few days by hand.

The firm scum layer at Hagen is skimmed off and removed once a year. This statement, however, refers only to that portion of the installation which is not equipped for gas collection. The same was formerly the case at Essen-Rellinghausen. At this plant rails were laid for this purpose next to the digestion compartments. Since the building-in of a gas cover which holds the scum under water, this operation is no longer performed. At Kettwig the solid scum layer must be removed twice a year. It consists chiefly of wool grease from a cloth factory. Part can be drawn off in a wet state, so long as it has not become too dense. This plant is now being arranged so that the scum can be drawn off through sludge pipes at short intervals before it has become too dense. The scum is then digested together with bottom sludge in a heated digestion tank.

At Iserlohn, the scum is pumped out twice a year, likewise at the older part of the plant at Hagen in which the Imhoff tanks are equipped for

gas collection. A portable diaphragm pump is used. At Hagen bottom sludge is sometimes pumped into the scum.

Conclusions

Foaming of Imhoff tanks need not be taken into account at all. During the ripening period it is prevented with certainty by seeding and during later periods of operation by keeping the sludge level below the slots. Scum formation is not encountered in two-thirds of the plants. In one-third of the cases, however, it needs to be taken into account. In small works the scum may be skimmed off once a year and removed. In general, however, it is more convenient, especially in larger works, to force the scum to sink by breaking it up and wetting it. In plants subject to scum formation, *i. e.*, those of inadequate capacity or those treating industrial wastes of special composition which create appreciable scum, special provisions are recommended in order to maintain the scum in the liquid state and to permit its withdrawal when needed. This purpose may be served, for example, by flushing devices consisting of water pipes and draw-off pipes built into the gas domes. The liquid scum which is drawn off or pumped out is then either introduced into the bottom sludge of the Imhoff tanks or, better, is treated in heated separate digestion tanks together with bottom sludge. According to the proposal of Buswell, sludge-compartment liquor may be employed for flushing. The flushing effect may be aided by placing under the gas collectors simple stirring devices for hand operation—this, too, in accordance with American example.

The sedimentation effect of the plant cannot be disturbed in any case.

Stream Pollution from the Operator's Point of View[1]

BY EARLE B. PHELPS[2]

The prevention of stream pollution requires activities of many sorts. In any logical and successful program there must first be scientific experimentation followed by suitable legislation based upon practicable engineering possibility. Many well-intentioned legislative programs of the past have been nullified by failure to keep them within these bounds. Broad general prohibition of stream pollution without reference either to the necessities of a local situation or to the possibilities of present-day practice becomes a dead letter even at its inception.

After this basis of scientific development and sound legislation has been laid, there must come local ordinances by the community or similar action by an industrial corporation, then engineering study of the local problem leading to plant design, next construction of the works and finally operation and maintenance. Stream pollution may result from the failure or short-comings of any of the links of this chain of events and each of them calls for most thoughtful consideration and an occasional check-up to keep it fully abreast of the times. But by far the most common, the most insidious and the most costly failure is failure in operation due to the lack of capable, intelligent and interested supervision or, in many cases, to no supervision at all.

It is a gratifying sign of the times that the position of sewage works operator is now fully recognized as one of dignity and one of responsibility; that it is now included in the classified civil service in certain states; that examinations of increasing degree of thoroughness are being required; and that special schools for training are now being provided. Even more indicative of the growing realization of the importance of the operator is, I believe, the formation of sewage works associations with their central Federation and Journal and the local meetings of small groups. A fundamental aim of these associations is to provide a common meeting place for the scientific investigator, the designing engineer, the administrative engineer of state and city and the man upon whom rests the final responsibility—the operator, that each may learn of the others' viewpoint and profit by the others' experience.

Stream pollution from the operator's point of view is no different from an engineer's or any other citizen's, but the operator's responsibilities are unique and it will be our present purpose to outline these, not in terms of routine details of management but in broader terms of causes and effects,

[1] *Presented at the Fall Meeting of the New York Sewage Works Association, Syracuse, Sept. 13, 1930.*

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of scope and of limitation. It is always well to start with definitions in order that we may have clearly before us the meaning of our words.

Stream pollution is a complex phenomenon which must itself be analyzed before we can proceed to its discussion. Purity is only relative and impure water is impure only with regard to a certain use to which it is to be put. The salts of calcium, constituting hardness in water, are a far more serious impurity for steam boiler purposes than are typhoid fever germs; the paper mill superintendent cannot tolerate muddy water and other industries have their specific requirements. To each of these "impurity" and "pollution" represent very different conditions, and all of them differ from the domestic user whose specifications call first of all for a water free from pathogenic organisms and also from certain other undesirable constituents. Pollution then must be classified upon this same basis. It assumes one or another characteristic according to the uses of the stream below. Preventive measures, if wisely undertaken, are likewise based upon such a classification. We will undertake, therefore, to define pollution in certain of the more important classifications which lead to nuisance of definite types.

The type most common to all waste, industrial as well as municipal, is that due to suspended material which may either float upon the surface or deposit upon the sides and bed of streams in the form of sludge. We view this material in its present classification merely as a physical state of matter regardless of its chemical nature. It fills up slack-water pools, forms unsightly deposits along the shore line or floats as oil or debris upon the surface. Minimum treatment in any plant calls for the use of coarse or fine screens for the removal of debris and of tanks for the more or less complete removal of solids capable of settling. When additional treatment is provided it is still generally economical to use these devices because of their efficiency in the removal of constituents otherwise most difficult to handle. In these instances they become preliminary processes, but they have also definite usefulness as major processes in themselves.

The determination of suspended solids capable of settling is done by the use of an Imhoff cone. This test is the simplest representative of a type of test which yields a direct numerical value of the thing measured rather than an indirect measure generally meaning little to the uninitiated. The reading of the cone can be simply converted into cubic yards of sludge per million gallons of sewage so that the test is useful in measuring the total effectiveness of the tanks as a preventive for one type of pollution and also in measuring the relative efficiency on a percentage basis.

At this point we may pause for a moment to consider a common source of weakness in plant operation. Where filters follow tanks it may seem that any excessive quantity of suspended matter passing through the tanks by reason of careless operation will be handled by the filters. This is true to a certain extent and will get the operator by for a while at least. It is,

however, undoing the engineer's careful design and throwing a load upon the wrong part of the machine. It will eventually result in lowered efficiency of the filters which in turn will pass on to the next stage or stages an increased deficit so that shortly the plant is unbalanced and on its way to failure. I would write as a first maxim for operators: Neglect of an early stage of treatment at the expense of a later stage leads to costly inefficiency.

A second type of pollution in our general classification is organic matter capable of fermenting in the stream. We have dealt with a physical property, suspended matter; now we deal with a chemical property, putrescibility. It is of no significance that these properties may overlap; that suspended matter may also be putrescible. We are dealing here with a classification of properties which lead to types of stream pollution and upon which rational sewage treatment must be based. Organic pollution is in general much more serious than mere physical deposit. It is that which appeals to the sense of smell as the other appeals to the sense of sight. It results in conditions most commonly thought of in connection with pollution but it is by no means the unique feature that it is oftentimes thought to be.

Natural waters carry in solution, along with various other mineral and organic constituents, a certain quantity of atmospheric oxygen, known to water chemists as dissolved oxygen or simply D. O. If water be heated, the dissolved oxygen, together with other gases, will be seen to escape in tiny bubbles just as the boiling point is reached. After boiling, if the water be cooled and exposed to the air in a shallow vessel it will reabsorb the atmospheric oxygen up to an amount known as the saturation value. The lower the temperature the higher is this saturation value.

This little experiment illustrates just what happens in a polluted stream. Fermentation of organic matter uses up oxygen at the expense of the D. O., exposure to the air results in what we term reaeration. In any stream the existing condition as regards D. O. is the resultant of the two opposing forces of deaeration, due to organic pollution, and reaeration. In deep, slow-moving streams the latter becomes of slight moment and pollution exerts its maximum ill effect. Shallow, swiftly running streams on the other hand have a high rate of reaeration and can, therefore, handle pollution with a minimum of damage.

This chemical property of putrescibility is dealt with in sewage treatment by oxidizing devices such as filters or the activated sludge process. These do the work which would otherwise fall upon the stream but do it much more quickly and thoroughly. The laboratory control of these oxidizing processes is again a direct test, reading in terms of the thing which we desire to measure. It is the so-called biochemical oxygen demand test, known more commonly as the B. O. D. The stream conditions are deter-

mined by oxygen relations and the B. O. D. is read in terms of oxygen. The operator can therefore compute the effect of the treated sewage upon the stream in these terms. It is necessary to understand clearly, however, the nature of this oxidizing reaction in order to interpret the results.

Like all chemical reactions this one involves a time and temperature condition. In the laboratory, for convenience, the test is done at 20° and generally over a 5-day period. This gives a single value, the amount of oxygen that the sewage will take from the stream in the course of five days after its discharge if the temperature of the stream be 20° C. (68° F.). Now it may happen that within two days the stream will reach the ocean, or another stream providing ample dilution, and of course the temperature of the stream will vary. Fortunately the properties of this reaction have been so thoroughly studied that starting with the standard B. O. D. as determined in the laboratory we can by a simple formula deduce the actual effect upon the stream after any lapse of time and at any temperature whatever. I append a conversion table by which one may determine the B. O. D. that will be exerted by a sewage or effluent over any period of time up to ten days and at any temperature between 0° and 28° C. from the value of the standard test, five days at 20° C. In the table the standard value is placed at unity so that all other values are relative to the standard.

The standard tests also give directly and without further computation, the relative efficiency of the plant as a whole or of any portion of it if determinations made upon the influent and the effluent are compared. In this way it will be found that the tanks also have a function in the reduction of putrescibility althought they do it by physical removal, whereas the filters actually destroy material by oxidation.

We come next to a third important type of stream pollution which is bacterial. Unlike the physical and chemical pollutions which are common to sewage and most industrial wastes, bacterial pollution is almost a unique property of city sewage. This is the pollution most important from a public health point of view and least important from the points of view of the appearance of the stream, the maintenance of fish life, and industrial uses. While the true harmfulness of bacterial pollution lies in the danger of the presence of pathogenic bacteria and their possible effect upon water supplies, shellfish areas, and bathers, we actually deal with bacteria in general as indicative of dangerous forms.

Here again we find in treatment works special processes for dealing with this type of pollution and also some overlapping of function whereby the devices designed for other specific purposes serve incidentally to reduce the bacterial content. Trickling filters bring about an incidental reduction which may amount to 50 per cent or more and the activated sludge process is even more efficient in this respect. The specific treatment against bacteria, however, is chlorination. This is applied as a final treatment

RELATION OF TIME AND TEMPERATURE TO THE BIOCHEMICAL OXYGEN DEMAND OF SEWAGE
(5 DAYS −20° B. O. D. = UNITY)

Time	Temperature (° C.)														
Days	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28
0.25	0.033	0.036	0.039	0.043	0.047	0.051	0.056	0.062	0.067	0.073	0.080	0.089	0.096	0.105	0.116
0.50	0.065	0.071	0.077	0.084	0.092	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.20	0.22
0.75	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.33
1.00	0.13	0.14	0.15	0.17	0.18	0.19	0.21	0.23	0.25	0.27	0.30	0.33	0.35	0.38	0.41
1.5	0.19	0.20	0.22	0.24	0.26	0.28	0.31	0.34	0.36	0.39	0.43	0.46	0.50	0.53	0.57
2.0	0.24	0.26	0.29	0.31	0.33	0.36	0.40	0.43	0.46	0.50	0.54	0.58	0.62	0.66	0.70
3.0	0.35	0.38	0.41	0.44	0.47	0.52	0.56	0.60	0.64	0.68	0.73	0.78	0.82	0.87	0.91
4.0	0.45	0.49	0.52	0.55	0.59	0.64	0.69	0.73	0.78	0.83	0.87	0.92	0.97	1.0	1.1
5.0	0.54	0.58	0.62	0.66	0.70	0.75	0.81	0.86	0.91	0.96	1.0	1.0	1.1	1.1	1.2
6.0	0.62	0.66	0.71	0.75	0.80	0.85	0.90	0.95	1.0	1.0	1.1	1.1	1.2	1.2	1.3
7.0	0.69	0.74	0.79	0.84	0.88	0.93	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3
8.0	0.76	0.81	0.86	0.90	0.95	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3
10.0	0.87	0.92	0.97	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4
Infinity	Ultimate demand − 1.455 at any temperature														

$$\text{B. O. D.} = \frac{1-10^{-Kt}}{0.684};\ K = 0.1 \times 1.047^{T-20}$$

t = time (days)
T = Temp. ° C.

following oxidizing processes or after tank treatments or, at times, as the sole treatment. The particular arrangement best suited to the local situation is determined by the engineer upon the basis of the local requirements and of the most economical manner of satisfying them.

The laboratory control of chlorination, or indeed of any process capable of removing bacteria, is again by a direct test, the bacterial count. A somewhat simplified procedure, the *B. coli* determination, is often employed, a specific organism characteristic of sewage being made the basis of a quantitative determination. In either case the actual quality of the final effluent and the relative improvement brought about by the various stages of the plant are determined in direct terms of the thing concerning which the treatment is undertaken. We have a simpler test, which is merely indicative of satisfactory operations, in the so-called *o*-tolidine test, a test for excess chlorine. It has been found by experience that under the operating conditions of any given plant satisfactory bacterial removal will follow if a certain predetermined excess of chlorine is maintained at all times in the effluent.

Briefly summarizing we find that there are three major types of stream pollution against one or more of which protective measures may be applied. These are physical, chemical and bacterial. In sewage treatment we have types of works capable of dealing with each of these independently and any complete plant, that has been properly designed, performs a combination of these functions based upon the capacities, the limitations and the uses of the stream into which the effluent must be discharged. The operator should have knowledge of these down-stream conditions and of the extent to which his plant is expected to deal with the various types of pollution. He should be provided with tests corresponding to the three types of treatment, namely, the test for settleable solids, the test for B. O. D. and the test for bacteria, or as many of these as his plant is supposed to deal with. He should know that the function of one unit of the plant cannot be transferred to another unit without wastefulness and inefficiency. These are his responsibilities and duties as an operator, but every plant operator has an opportunity which is the envy of those scientists who are advancing the cause of sewage treatment by laboratory and small-scale experimental studies. He has at his disposal for experimental observation, a full-scale plant working under normal operating conditions day and night throughout the year. He has the opportunity to observe the effect, first, of the normal fluctuations in quantity and quality of sewage, and second, of experimental modifications which he is in position to make looking toward the betterment of his output. By cultivating habits of observation, of testing and of recording he may become the investigator and thereby in addition to doing well his set task, contribute scientific information of value in the development of the art.

Past and Present Developments in Sewage Disposal and Purification[1]

BY H. W. CLARK[2]

Water purification and sewage purification have been the sanitary engineering subjects of greatest interest during the last forty years. Numberless investigations have been made all over the civilized world and an ever-increasing volume of literature on these subjects is being published yearly in engineering, chemical and other technical journals. I believe that a clearing-house of some kind should be established to separate the valuable work from that of little or no value. Those of us who have been interested in sewage purification for many years constantly, as Kipling remarked in regard to Homer's listeners, "hear old songs come round again," simply dressed up in new words; that is to say, much of the research of past years is rediscovered by new workers and given to us again. Moreover, the mass of undigested research work with conclusions based on too short a period of experimentation is often misleading to the sanitary engineer who wishes to keep up with the times but cannot afford to spend the money of municipalities without being well assured of satisfactory and economical results.

Sewage disposal forty years ago was largely confined to three methods—dilution, chemical precipitation and sewage farming, although some work had been done on intermittent sand filtration, and a few sand filters were in operation.

Rafter and Baker's "Sewage Disposal in the United States," published about 1890, contained an exhaustive description of some forty sewage disposal plants actually built in the United States and Canada, with many details in regard to cost, methods of operation and results. Last year the *Engineering News-Record's* publication, entitled "Engineering Construction Markets," gave a list of 2828 treatment plants in the United States alone, in operation in thirty-seven states, some, of course, being very crude and inadequate. In the Rafter-Baker book the statement was made that sewage disposal in its practical application was comparatively a new subject in the United States but that the rapid growth of population, especially the growth of cities and towns, had resulted in a marked increase in the discharge of water, containing human excrement, into water supplies. Massachusetts was represented in the book by quotations from and discussions of the early work of the Lawrence Experiment Station of the Massachusetts State Board of Health and by descriptions of sewage treatment plants at South Framingham, Marlborough, Medfield and Worcester.

[1] *Presented before New England Health Institute, Boston, Mass., April 15, 1930.*

[2] *Chief Chemist, Massachusetts Department of Public Health.*

It is a long journey from the plants of that period to the Imhoff tanks, trickling filters and activated sludge plants of the present day and to the many variations or combinations of these methods now in use. Today in Massachusetts we have good examples of disposal by dilution, of intermittent filtration and of trickling filters operating on a large scale. There is also prospect of an activated sludge plant being built in the near future.

Forty-two years ago Dr. Drown, then chief chemist of the State Board of Health and head of the Department of Chemistry at the Massachusetts Institute of Technology, asked me one day to take the position of junior chemist at the Lawrence Experiment Station, then being organized for experimental work on sewage and water. The Station was established through the wisdom and far-sightedness of Dr. H. P. Walcott and Hiram F. Mills, C.E. The first two or three years at Lawrence under Hazen, Mills and Drown were full of interesting discussions and planning of work which would develop the principles of biological purification of sewage and make known the fundamental laws necessary for successful purification by intermittent filtration. The standards of purification set by Mr. Mills were high. His 1890 report entitled "Purification of Sewage and Water" is still much in demand. In this report he described the difference between intermittent and continuous filtration and stated "the process of purification in intermittent filtration has been called an oxidizing process, or, more familiarly, a burning; but the chemical products of burning, or rapid dry oxidation by means of heat, are not the same as the products of wet oxidation occurring in the thin laminæ of the liquid, covering the particles of sand, in contact with air within the filter. Here nitrification occurs, that is, nitric acid is formed from the nitrogen of the organic matter and the oxygen of the air; and this strong acid immediately combines with the potash or soda or lime or other base in the sewage, forming nitrate of potash or of soda or other salt."

Following Mr. Mill's 1890 report, the reports of 1891 and 1892, written by Allen Hazen, summarized the work up to that date and Hazen from his own work formulated certain laws necessary to follow in the construction and successful operation of intermittent sand filters. These laws have too often been forgotten.

The work was continued by George W. Fuller, chemist in charge of the Station from July, 1893, to September, 1895. Previously Mr. Fuller had been in charge of the Biological Laboratory. Since then the writer has been Director of this Station. Practically everything studied in sewage purification during those first years was upon intermittent filtration through sand, although filters of gravel-stone had been put in operation in 1889. When, in 1908, the writer and his then assistant, Mr. S. DeM. Gage, published a review of twenty-one years' work at the Station, about one-third of this review was devoted to the same subject, namely, intermittent

filtration through sand, but many pages were given to summarizing the work of the Station on contact filters, trickling filters, septic tanks, gas production, sludge disposal in different ways, including destructive distillation, chemical precipitation and many other subjects.

Disposal by Dilution

Disposal by dilution, although an early method adopted with the introduction of sewerage systems, is still used wherever it is possible to do so without causing a nuisance or endangering health. The total volume of sewage produced in this country can hardly be estimated but undoubtedly disposal by dilution would account for almost 90 per cent of it even today. Massachusetts had a population of 4,140,000 people in 1925. One hundred and fifteen towns have sewerage systems serving practically 85 per cent of the people of the state but the sewage of only about 12 per cent of the inhabitants of the state is treated upon sewage disposal areas. The only large city in the state with sewage treatment is Worcester, although Brockton, Pittsfield and Fitchburg also have treatment works. The domestic sewage and industrial wastes of the Metropolitan District, including Boston and twenty-one surrounding cities and towns, is discharged into Boston Harbor through three outlets. The average daily discharge is 260,000,000 gallons. This volume is so great that a commission has been appointed to investigate harbor disposal and to determine whether or when certain portions of this great volume of sewage must be, by the extension of the outlets, discharged outside of the harbor or whether treatment before discharge must be adopted. The reason for this investigation is largely, if not entirely, due to the objectionable appearance of certain parts of the harbor rather than to any serious nuisance along the shores, although troubles of this kind do occur. Odors near the outlets are not due to exhaustion of oxygen in the harbor water by polluting organic matter, as certain observers formerly stated; in fact, water into which sewage enters can be deprived of all its oxygen before noticeable odors occur.

Value of Sewage and Sewage Sludge

We are hearing a great deal today in regard to the value of sewage and sewage sludge and our great wastefulness in not utilizing all its fertilizing value or at least not recovering the valuable material of the sludge. We and our predecessors heard the same cry thirty, forty and fifty years ago. It is being repeated now very largely because of the Izaak Walton League, which is active in many ways in its desire to preserve fish life, whatever the cost. What is the value of sewage and sewage sludge? In an article written by me seventeen years ago entitled "The Fertilizing Value of

Sewage and Sewage Sludge—a Sanitary and Economic Problem," the value of sewage was thoroughly discussed. Computations in that article indicated that a million gallons of average sewage contained about $60 worth of fertilizing material and about $7 worth of fatty matters. Two-thirds of this value was represented by ammonia in solution. The sludge produced from a million gallons of sewage was worth about $20, theoretically. It was stated that no successful method of recovery of these materials of undoubted value was in operation. The old idea was that the sewage was valuable for farm purposes and hundreds of sewage farms, ranging in size from a few to many thousand acres, were in operation twenty years ago when I studied this subject in England and on the continent. In all this study hardly a farm was found that paid. England at that time was beginning to take up contact and trickling filters and other modern methods for purifying sewage, which were almost always located on or near the municipal sewage farm. Sludge was then and still is being used to fill in lowlands, banked up and covered with sod, dumped into abandoned mines, taken out to sea in sludge boats, or piled up in the nearest convenient location. In that article I stated that in order to reclaim the valuable material in sludge, it must, after separation from the liquid, be dried, pressed and subjected to other processes for the separation of the fertilizing material from the fatty matters. At the present time the recovery of sludge as a source of profit is practised in a limited way in a couple of English cities but we have one notable example in this country, namely, Milwaukee, where the sludge from the activated sludge process is being recovered, dried, ground and sold for upward of $20 to $28 per ton, according to the amount and destination. From eighty to one hundred tons of dried material are being produced daily and sold as fast as produced. During 1929 there were sold from the Milwaukee plant 31,602 tons of Milorganite—the name given this prepared sludge—for the sum, after all selling and distributing expenses were paid, of $611,786.32. What the cost of preparation is I do not know nor the cost of recovery. While this might appear to be a good example to follow, if New York, Chicago, Philadelphia, Boston and other large municipalities all over the country should undertake to construct activated sludge plants and reclaim and sell sludge, the value of the product would, I believe, inevitably decrease to a point at which these cities could hardly afford to operate sludge recovery plants. There is also a question as to the grade of product which can be made. The nitrogen content varies considerably, particularly where the combined system of sewerage is used and inert mineral matter from storm-water flow dilutes the nitrogen content of the dry-weather sludge.

It is easy to talk of this great waste and the desirability of preventing it but it is a long journey to the year when a considerable percentage of it will be saved and sold at a profit.

Sludge Detention and Digestion

If sludge cannot be sold it must be handled and disposed of as inoffensively as possible. I have often called attention to studies upon sludge concentration and digestion in a separate tank, begun at the Experiment Station in 1899. In this work sewage was settled in an upper tank and then the sludge allowed to pass into a lower tank. Then came the double-deck tank of Imhoff, which was an improvement at that time over the crude double tank arrangement used by us at Lawrence. But from 1899 on we have experimented on sludge digestion in tanks of various shapes and sizes, the largest being of the Imhoff type and holding approximately 1250 gallons. In 1912 and 1913 some special experiments were made in tanks 17 and 30 feet deep with sludge of different kinds from different sewage and with the addition of lime, iron salts and other chemicals. In those early experiments it was noted that stirring the sludge aided and was beneficial to continuous digestion and attention was drawn to this fact. This is of interest now as mechanical stirring or mixing of sludge in separate digestion tanks is becoming a standard practice. We found, also, that the addition of iron salts aided the beginning of fermentation and the production of a more or less odorless sludge in Imhoff and other sludge tanks. Apparently the addition of lime was of little or no benefit in the digestion of the sludge we used. This was another fact which has been substantiated in recent years; that is, sludge from Lawrence sewage at the Experiment Station will always ferment rapidly without adjustment of reaction by lime. The reason for this has been explained by us in articles upon sludge digestion and is undoubtedly due to the low amount of carbonaceous vegetable matter in this sludge.

Much work on sludge digestion has been done in recent years by Rudolfs, Fair and by us at Lawrence. Rudolfs' work is by far the most elaborate and on the largest scale. We have differed somewhat from both Fair and Rudolfs in certain particulars; that is, it does not appear from our work that the results obtained in one set of experiments, with the sludge of one municipality, can always be applied to the sludge of a second municipality. Our results indicate to us that pH, temperature and inoculation with ripe sludge are not always the controlling factors but that the chemical composition of the organic matter of the sludge is the real controlling element. This was elaborated by us in an article in *Industrial and Engineering Chemistry* in March, 1929. Our work also indicates that organic acids are not injurious to actively fermenting sludge. They may delay the beginning of digestion but sometimes they actually aid fermentation and digestion. The addition of acetic acid in one sludge experiment aided fermentation and digestion very materially.

All our experiments show that the rise in pH value of digesting sludge is due to calcium carbonate released by the destruction of the organic

matter of the sludge by gasification, in much the same way as if the sludge were burned. On page 51 of the *Report of the Massachusetts Department of Public Health for 1927*, it was shown that calcium carbonate was formed during digestion of sludge, and it was pointed out that this was one of the causes of increased pH as digestion progresses. Destruction of organic acids and formation of ammonium carbonate are other contributing factors. One experiment on this study was as follows: Twenty gallons of Lawrence sludge and twenty gallons of Brockton sludge were placed in tanks 8 inches in diameter and 8 feet deep, and the pH, alkalinity of the liquid to methyl orange, and calcium in solution as carbonate were determined at intervals of several days. The alkalinity of the Lawrence sludge at the beginning of the experiment was 30 parts in 100,000 and reached a maximum of 107 after forty-two days and then decreased to a constant value of 95 after one hundred and forty-two days. The pH at the start was 6.9 and reached a maximum of 7.3 in about forty-two days and finally declined to 7.0. The calcium carbonate in solution at the start was 7.8 parts per million and reached a maximum of 41.5 parts after forty-two days and decreased to around 30 parts. The changes in Brockton sludge were similar in point of time. The alkalinity went from 36 to 106, the pH from 6.1 to 7.2 and the calcium carbonate from 10.1 to 29.3. Apparently, a considerable part of the methyl orange alkalinity is due to ammonia, since the calcium carbonate is not sufficient to account for the increase. The amount of calcium carbonate in the form of bicarbonate that can be present is limited by its solubility. Lawrence sludge at the end of digestion has often contained from 3 to 5 times as much carbonate as the same sludge when entering the sludge digestion chamber. Our large Imhoff tanks after several years' operation show an increase in the pH of the sludge from 6.8 to 7.2.

Intermittent Filtration

Intermittent filtration through sand has been the most favored method of sewage disposal in New England for many years. Massachusetts has twenty-five municipal areas of this kind, most of them fairly well operated and they remove perhaps, with their sludge settling tanks, 90 per cent or more of the organic matters of the sewage. Certain important factors in regard to the construction and operation of sand filters have too often been overlooked or neglected. These factors were well studied, developed and explained by Allen Hazen in the Lawrence Experiment Station reports as early as 1891 and 1892. For instance, studies were made of the relation of the sewage applied to a given area and the character of the sand of which the filter was made, with due consideration for the open space in the sand and the volume of air held. Nevertheless, many of the municipal acre or half-acre beds of the sand areas of New England and elsewhere

receive daily applications many times as great as they can satisfactorily and economically purify, while other beds at the same area remain unused day after day; that is, distribution of sewage is poorly done. In the report of the Lawrence Experiment Station for 1908 the valuable experience gained by twenty-one years' operation of experimental sand filters at the Station and studies of municipal filters was summarized in a series of chapters dealing with almost every phase of sand filtration; the work of later years has confirmed the conclusions given then. The operation of a sand filter may be destroyed by stratified sand layers. This has been the trouble at certain areas where sand in place was used and only trenches dug for the placing of underdrains. The area at Clinton is a good example of this mistake.

One of the results of perfect sand filtration is the production of large amounts of nitrates. The purified effluent containing these nitrates often causes trouble in streams owing to the encouragement the nitrates give to vigorous microscopic growths. Disagreeable appearance of these streams and disagreeable odors sometimes result. One method which might perhaps be used to prevent this has been developed at Lawrence of late years, namely, passing the effluent high in nitrates over or through sludge digestion tanks. The sludge is stabilized and the nitrates reduced. The effluent flowing from our tank was of good appearance and quality and only a small amount of the nitrogen of the nitrates appeared as free ammonia in the effluent, which was still clear and very largely rid of its organism-producing character.

Trickling Filters

Trickling filters on a practical or municipal scale have been in use for more than thirty years. They are the outgrowth of certain experiments on filtration at the Lawrence Experiment Station, where gravel-stone filters operated at a comparatively high rate were started in 1889, more than forty years ago. Following these first gravel-stone filters, filters of coke, clinker, cinders and other material were constructed at Lawrence and the rates at which they were operated increased from time to time until in 1896 such filters, 5 feet in depth, were being operated at 1,000,000 gallons per acre daily with natural aeration; the first filters, with gravel-stone media, having had air drawn through them. The Lawrence work with trickling filters of different materials and different depths and rates of operation has been continued until the present time, and one trickling filter put in operation at Lawrence in 1899 is still at work, giving good results. I believe the first unaerated trickling filters on a municipal scale were constructed at Salford, England, by Corbett, who stated to the writer when visiting him in 1908 that he based his work on the results obtained in Massachusetts. This was also the statement of Dunbar,[1] the Director

[1] *Principles of Sewage Treatment* by Dunbar and Calvert, page 25.

of the Hamburg Hygienic Institute in those days. The construction of trickling filters on a municipal scale began to be active just about the time when contact filters were much exploited and just after Manchester, Sheffield and other English cities had built large areas of contact filters. When in 1908 I first saw the Manchester contact filters they were planning to change a part of the area to a modified form of trickling filter and other English towns having contact filters at that day, such as Sheffield, have discontinued them for other forms of treatment. Even in 1908, England was pretty well spotted with trickling filters and at Birmingham the sewage of 600,000 people was being cared for on filters of this type. The sewage was applied to these filters by many different kinds of traveling distributors and also by sprinkler nozzles. The sprinkler nozzle was apparently gaining in favor at that time but nearly every area which I visited, with the exception of Birmingham, had some form of traveling distributor varying with the size and shape of the filter bed from a simple form of distributor to the heavy, electrically propelled kind, which I understand is still in use at Hanley. I judge, moreover, from English engineering journals that traveling distributors are still being installed. Some claim they give better distribution of sewage than is obtained with filter nozzles, but American engineers have not considered them adapted to our climate or our large trickling filter areas. Cost also enters into this. A few small trickling filters are in operation in Canada to which sewage is applied by means of rotary distributors. These are generally housed and then they are said to work successfully even in Canadian winter weather, at Lethbridge (Alberta), Regina (Saskatchewan) and Dundas (Ontario), with temperatures as low as 40° below zero.

One of the principal studies made at Lawrence and elsewhere has been upon the most effective and economical depth of trickling filters. At Lawrence it has been proved to our satisfaction, at least, that a filter 10 feet deep will allow rates of filtration not simply twice as great as a filter 5 feet deep but even up to four to five times as great, with equal degree of purification. Our studies along this line and conclusions in regard to depths were first published in 1915 and the work has since been repeated, with confirmation of the early results, this repetition being made largely because of the work of Buswell in Illinois, who apparently obtained contrary results. His bulletin on this subject, No. 26 of the *Illinois State Water Survey* series, stated that trickling filters over 6 feet in depth are uneconomical, as the greatest degree of purification is in the upper portion of the filter. It is, of course, true that the greatest degree of purification generally takes place in the upper portion of a filter as the least stable organic matters, large in amount, are acted upon first by the bacteria, leaving the more stable matters to be treated more slowly in the lower portions of the filter. Buswell states that we at Lawrence

assume equal purification per foot of depth which is just what we do not assume or say as that would not even be expected. We have, however, in our reports, stated for comparison the number of gallons per foot of material the various filters will treat successfully but without even implying that each foot did an equal amount of work. Buswell quotes results from 1914 to 1918, inclusive, for four of our filters, 4, 6, 8 and 10 feet in depth to illustrate his point but he draws a wrong conclusion. Taking the average results of these Lawrence filters from 1914 to 1917, inclusive, when the degree of purification obtained was the same, each foot of the 4-foot filter filtered 93,000 gallons per acre daily and each foot of the 10-foot filter 358,000 gallons per acre daily; in other words, the 10-foot filter handled successfully four times as much sewage per foot as the filter 4 feet in depth and we are still getting the same results. In regard to Buswell's statement that practically all purification takes place in the upper foot or two of a trickling filter, we can point out results from a filter operated by us 31 years ago, consisting of five trays of filter media each 10 inches deep. Analyses showed progressive nitrification in each section. This has been shown by other filters, 6, 8 and 10 feet in depth. With Lawrence sewage our work showed the advantage of the increased rates made possible by the construction of deep filters and also that a deep filter, on account of its reserve capacity, cares successfully for variations in the strength of sewage and changes in temperatures. We have in this state four examples of municipal trickling filters, namely, at Fitchburg, Worcester, Brockton and Milford. The Fitchburg filters, built in 1913 from the design by Metcalf and Eddy, were made 10 feet deep on the basis of our Lawrence work.

Activated Sludge

We claim that the activated sludge process was discovered and put into operation by us at Lawrence in 1911 and 1912 and our work in bottles, carboys and small tanks has been described many times. There are two very important patent suits, however, now under way, brought by Activated Sludge, Inc., against The Sanitary District of Chicago and the City of Milwaukee, this corporation claiming that the activated-sludge process in its present form was discovered by, patented by and belongs to an Englishman named Walter Jones. The case against The Sanitary District of Chicago has been under way for five years—the Milwaukee case a shorter period. In both, volumes of testimony have been given by English and American experts. The arguments, I believe, were made in the Milwaukee case a year ago.

From the early principles discovered at Lawrence and the development of methods for using the process on a large scale great plants such as those at Milwaukee and elsewhere have been constructed. At Milwaukee nearly

$800,000 has been expended up to the present time in research work having to do not only with the process itself but also with the recovery of sludge. The entire plant up to the present time has cost in the neighborhood of ten million dollars. They are very optimistic at Milwaukee and hope to reduce the cost of operating the activated sludge plant one-half; if they are successful in this and continue to sell their fertilizer at a good price, the actual cost of operation will be nil, so they claim; that is, nothing exclusive of capital charges and depreciation.

Recently we have been much interested in the Chicago problem of sewage disposal owing to the program calling for an expenditure of $172,000,000 for sewage treatment plants and intercepting sewers in addition to $11,500,000 for the completion of certain contracts which are under way. Chicago has at the present time some large and interesting plants. The Calumet Sewage Treatment Works consist of an installation of Imhoff tanks, but two activated sludge units and a small trickling filter are in operation for experimental purposes. The West Side Treatment Works are designed for the treatment of the sewage of a population of 1,850,000 people and an average flow of 400,000,000 gallons of sewage a day. The initial installation consists of bar screens, skimming tanks, Imhoff tanks and sludge drying beds; land has been acquired for future extension of the tanks as well as for an activated sludge plant for completing the treatment. The North Side Treatment Works are of the activated sludge type and are designed for the treatment of the sewage from a population 800,000 with an average flow of 175,000,000 gallons a day. This is the largest activated sludge plant yet constructed.

Aeration Preliminary to Filtration

When we were successful at Lawrence in producing nitrification and stable effluents by aeration of sewage with live or active sludge (for the name "activated sludge" had not then been coined), we carried on some research work in regard to filtering this effluent through trickling filters in order to compare the effluent and the rate of filtration with effluents and rates of filtration of similar trickling filters receiving settled sewage. This work began early in 1913, seventeen years ago, and was continued for four years. We found, as others have since found, that by preliminary activation of the sewage (that is, a much shorter period than is required for nitrification) a trickling filter could be operated at an average rate as high as 9,000,000 gallons per acre per day, with production of an effluent equal to the effluent of the filter receiving settled sewage and operated at one-third this rate, namely, three million gallons per day. There certainly is opportunity for reducing the areas required by increasing the rates of filtration, if the applied sewage has been partly activated, as was found at Lawrence seventeen years ago.

Submerged Contact Aerators

One of the pieces of apparatus put in operation at Lawrence in January, 1913, was a tank containing layers of slate. In this tank the sewage was constantly aerated by means of a pipe at one end with many orifices through which air was continually forced. This caused the sewage to circulate through the tank. We also kept activated sludge in this tank which was also circulated but as we drew the purified effluent from the tank the sludge remained. This tank was put in operation as a result of our bottle work, in which we noted the effect of the sludge and growths. The slates were tried as an aid for the collection and growth of the live sludge.

Several years ago, Imhoff published an article in regard to apparatus of exactly the same kind to which he gave the name "submerged aerators." At the time of this publication, Langdon Pearse, in a letter to the *Engineering News-Record*, called attention to the fact that we had operated the same thing at Lawrence in 1913—some fifteen years before Imhoff's article. Imhoff states that these modern contact aerators or colloiders were based upon the investigations of Travis, Phelps, Buswell and others; but he neglected to include the Lawrence work of seventeen years ago.

In conclusion, the Lawrence work has sometimes been criticized as being carried on on a scale too small to be of great value. I believe the success which has followed the installation of municipal plants based on the principles demonstrated by our Lawrence experiments is the answer to this criticism. To obtain accurate data on cost of construction and cost of operation of large plants, experiments on a large scale are required as at Milwaukee, Chicago and elsewhere, where more ample funds have been made available for the purpose.

Conditions Affecting General Layout of Sewage Treatment Works[1]

BY PAUL HANSEN[2]

In designing sewage treatment works, engineers endeavor to forecast for a reasonable period in the future all of the factors that have a bearing on design. Principal among these factors are (1) population and population growth, (2) sewage volume, and (3) sewage characteristics. Unfortunately, these factors cannot be forecast with complete reliability. Consequently, it becomes important to design so that the installation and its several parts may be expanded and modified without undue awkwardness or undue expense to meet changed and unforeseeable conditions.

Each part of a sewage treatment installation should be carefully considered from the horizontal point of view (arrangement) and the vertical point of view (hydraulics). Then the several parts should be brought together and related to each other in a manner that will be convenient, promote good operation and allow adequately for future expansion and the interposition of new elements that may be found necessary in the light of experience.

Some future requirements are beyond the possibility of prediction but allowance may be made by proper arrangement of units more cheaply than providing excess capacity as a factor of safety. For example, tighter sewers added to the system will result in relatively more suspended matter as compared with flow and call for enlargement of sludge digestion capacity ahead of sedimentation capacity. New industries may increase organic matter in solution such as starch wastes and call for enlargement of bacterial capacity sooner than of sedimentation capacity.

These principles can best be illustrated by first discussing briefly the requirements of the main elements of sewage treatment works with reference to expansion and modification and then showing by a few diagrams how these several elements may be brought together to constitute a complete plant.

Bar Screens.—Bar screens are generally placed at the inlet to sewage treatment plants and pumping stations. Ordinarily manually cleaned screens of this type are sufficient and most economical. The sewage may, however, carry an unanticipated quantity of garbage, rags and trash which may render desirable the subsequent installation of self-cleansing screens with smaller openings. To permit this contingency, adequate space and head should be provided.

[1] *Read at Seventh Annual Meeting, Illinois Association of Sanitary Districts, Aurora, Ill., June 11, 1930.*

[2] *Pearse, Greeley and Hansen, 6 No. Michigan Ave., Chicago, Ill.*

Grit Chambers.—Grit chambers sometimes require expansion or modification because of larger quantity of grit or larger volume of sewage flow than originally anticipated. The hydraulics should be such that increased capacity may be obtained by increasing the depth of flow within proper limits. The horizontal plan should be such that increased capacity may be provided by additional grit channels. For sanitary sewers grit chambers are generally assumed to be unnecessary. Many sanitary sewers, however, carry considerable quantities of grit and grit chambers may find justification after the works have been built. It is accordingly desirable, therefore, so to place and arrange screen chambers that grit chambers or other grit removal devices may be added subsequently.

Measuring Devices.—In connection with grit chambers and screen chambers it is often feasible to provide measuring weirs. When such are built in connection with these structures, an allowance must be made for a suitable fall. It may not be out of place to mention at this point, that in all sewage treatment works suitable provision should be made for continuously measuring the flow of sewage, otherwise it is difficult to maintain proper observation and proper records of plant performance.

Oil and Grease Removers.—Oil and grease are troublesome at some sewage treatment works. It is not always practicable in advance to determine if grease removal devices are necessary. In many instances troublesome quantities of oil and grease may be effectively kept out of the sewers. Where there is any possibility of oil and grease becoming troublesome sufficient space should be left for oil and grease removal devices.

Sedimentation Tanks.—Adequate space for additional sedimentation tanks should be provided. This space should be adjacent to the initial installation of tanks as a means of facilitating operation. It is important that the hydraulics of the channels be carefully worked out to permit the future installations to function properly with the initial installation. Perhaps one of the most difficult elements in the design of sewage treatment works is the development of correct hydraulics for sedimentation tanks. It should be feasible to expand sedimentation tanks independently of other portions of the plant, inasmuch as an unanticipated large volume of flow may require enlarged sedimentation, but may not require enlargement of other elements of the plant. This is another reason also why the space for future expansion of sedimentation tanks should be adjacent to the initial installation.

Tanks of the Imhoff type are less flexible than sedimentation tanks operating in conjunction with separate sludge digestion tanks, with regard to meeting unanticipated large per capita flows or with reference to increasing sludge digestion capacity, when these two demands vary independently from the original design basis. However, if suitably

located space is provided for them separate sludge digestion tanks may be operated quite successfully in conjunction with Imhoff tanks.

Sludge Digestion Tanks.—Proper capacity for sludge digestion is one of the most difficult things to determine and one of the elements of the plant which is most likely to require expansion independently of other elements of the installation. For purposes of economy it may often be found necessary to restrict the initial installation of sludge digestion capacity as much as possible, relying on heating of the tanks with sludge-produced gas to accelerate the process. Where the digestion tanks are elaborated with stirring and gas collection devices, it is often desirable to provide a cheap type of storage tank to hold the digested sludge during winter months when drainage beds cannot be used. Both the digestion tanks and the storage tanks should be so located as to permit making suitable additions adjacent to the initial installation. The location of piping and valves for digestion and storage tanks should be carefully worked out to allow for exchanging and recirculating sludge among the several tanks for both initial and future installation.

Sludge Drying Beds.—Uncertainties with reference to volume of sludge production render it important to provide space adjacent to sludge drying beds for ample future extension. The location and arrangement of sludge drying beds should be considered with special care. The beds should be placed so that they are readily accessible and observable by the plant superintendent. They should be easily reached by well-graded roads to encourage farmers in removing the sludge from the beds, thus saving labor costs. In large works it is not often practicable to have farmers back their trucks or wagons onto the beds, in which case a narrow gage railroad system with dump cars may be necessary. Even so, the narrow gage railroad system should be designed particularly with reference to the final disposal of sludge.

Trickling Filters.—Because of the special arrangements required for dosing of trickling filters, it is usually not practicable, except in small plants, to design the trickling filter units so that they may be expanded merely by adding additional filters. The expansion is preferably made by groups of two filters, each group being served by the same dosing chamber. It is desirable, however, to have new units placed contiguously or nearly so. This also facilitates the hydraulics of the delivery conduits which must be carefully worked out to insure a proper division of flow to the several dosing chambers. The hydraulics within the filter group are quite complex and must be given careful study.

Activated Sludge Units.—Activated sludge units, together with final sedimentation tanks, are usually controlled from pipe galleries more or less suggestive of the pipe galleries used in water purification practice. It is very important, therefore, that adequate space be allowed for con-

tiguous expansion of the activated sludge units and the details of the piping and pipe galleries should be carefully worked out with this in view. The final sedimentation tanks in connection with the activated sludge process should be regarded as a component part of the activated sludge group units. In very large plants more than one group unit may be desirable. In view of developing knowledge in connection with the activated sludge process, it is desirable to design the units, in so far as practicable, with reference to their subsequent modification, to take advantage of any new progress in the art.

Final Sedimentation Tanks.—There is more latitude for placing final sedimentation tanks following trickling filters than there is for placing final sedimentation tanks following the activated sludge process. The latter have already been commented on. Final sedimentation tanks following trickling filters should be so placed that additions can be made as needed. The same principle with reference to unanticipated variations in flow applies here as in connection with the preliminary sedimentation tanks. Future extensions should be contiguous to initial installation for convenience in operation with particular reference to the removal of sludge.

Pumping Stations.—It is generally feasible to build pumping stations for sewage and for sludge of sufficient size to serve practically indefinitely. This merely requires provision of space for an adequate number of pumps to permit flexibility in operation, and pump emplacements suitably spaced to permit the substitution of larger pumps as needed. In small plants all pumping can generally be done at one station. In larger plants it is more convenient to have separate pumping stations for sewage and sludge, especially sludge from the final sedimentation tanks.

By-Passes.—A flexible system of by-passes should be provided so that sewage at any stage of treatment may be delivered directly to the stream or other body of water receiving the effluent. It is rarely desirable, however, to discharge unscreened sewage into a body of water. In most cases it is desirable to have primary sedimentation tanks in operation continuously. Where sewage must be pumped to secondary treatment devices such as trickling filters, it may be desirable to by-pass the secondary treatment as a means of economy whenever the dilution available in the stream permits such by-passing without objectionable results.

As activated sludge involves high operating costs it is desirable to by-pass this process whenever stream flow renders by-passing permissible, provided a sufficient quantity of activated sludge is retained and is available whenever by-passing may not be permissible.

General Arrangements.—The various elements heretofore described must be brought together in a carefully considered general arrangement that will not interfere with the operation and expansion of the several units in the manner already described. Further, the general arrangement

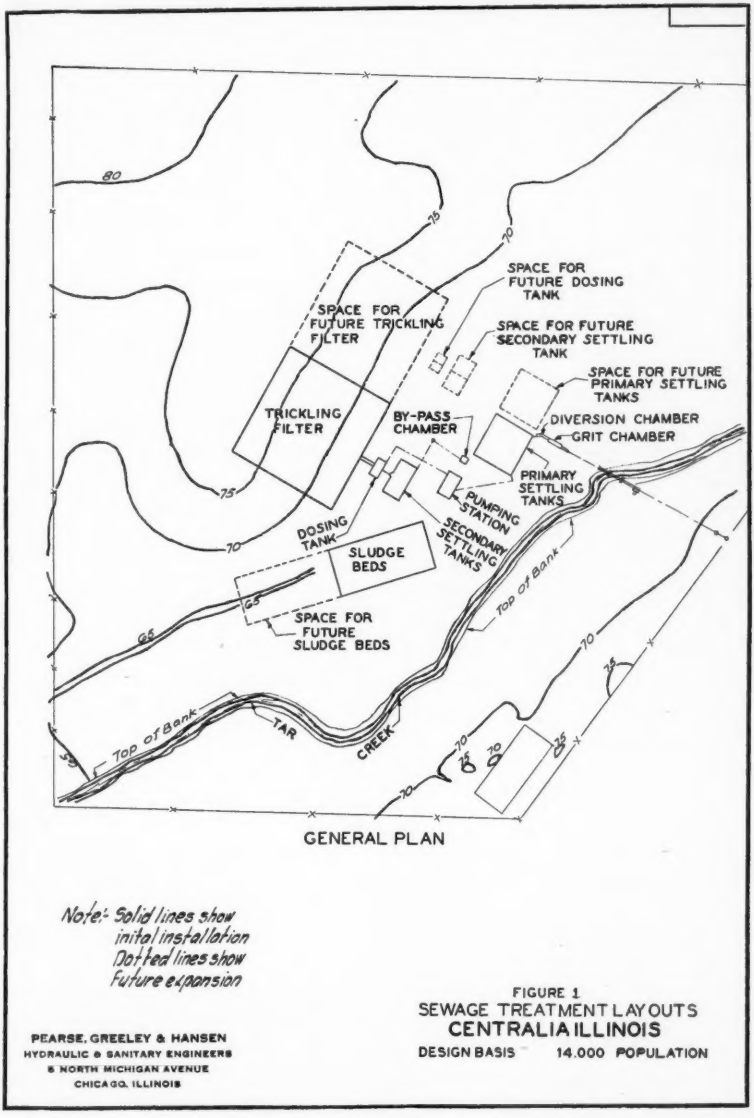
must take careful cognizance of the variations of the water level in the body of water receiving the effluent. The entire installation must be adequately protected against flood waters. Sometimes this necessitates surrounding the plant with a suitable embankment and providing pumping machinery for drainage and for lifting the effluent above high water. Ordinarily but not always it is desirable to have preliminary treatment above high water, though secondary treatment may be below the highest water, provided the secondary devices are adequately protected against damaging backwater.

In working out general arrangements two general types emerge. One may be described as the "centralized" type in which all operating elements are brought together in close proximity. Such operating elements include all of the pumping equipment for both sewage and sludge and devices requiring frequent operating control such as screens, grit chambers, dosing tanks, mechanical devices for sludge removal and sludge beds. In large installations all of these elements cannot be brought into close proximity, in which case what might be paradoxically called a "centralized decentralized" arrangement may be necessary. This implies that the operating control of each of the element groups should be brought together as much as practicable. More specifically it means that all of the operating control of sludge digestion tanks and sludge storage tanks should be at one location, that the operating control of sludge drying should be in one locality, that the operating control of sedimentation tanks, both primary and secondary, together with their respective sludge pumping stations, should be centralized as much as practicable. With plants of medium size there can generally be effected a compromise between the "centralized" arrangement and the "centralized decentralized" arrangement.

General arrangements of sewage treatment works are further modified by the shape of the treatment plant site and topography. A relatively level site or one with a gentle slope provides the maximum latitude in obtaining convenient arrangement. But with careful study it is generally possible to maintain a good arrangement while still conforming to local topography.

The hydraulics of the general arrangement must be such that the several elements or element groups will not interfere with each other and so that additional devices or treatments may be inserted where and when needed. For example, it may be found desirable to insert preliminary partial aeration of the sewage in the presence of activated sludge between sedimentation tanks and trickling filters. It may also be found desirable to insert grease catchers following grit chambers.

Special Cases.—The attached sketches illustrate applications of these principles in specific installations. Figure 1 is a trickling filter plant



proposed at Centralia, Illinois, in which it was practicable to secure a good "centralized" arrangement at the same time conforming to the local topography without sacrificing ample latitude in the future expansion of the plant.

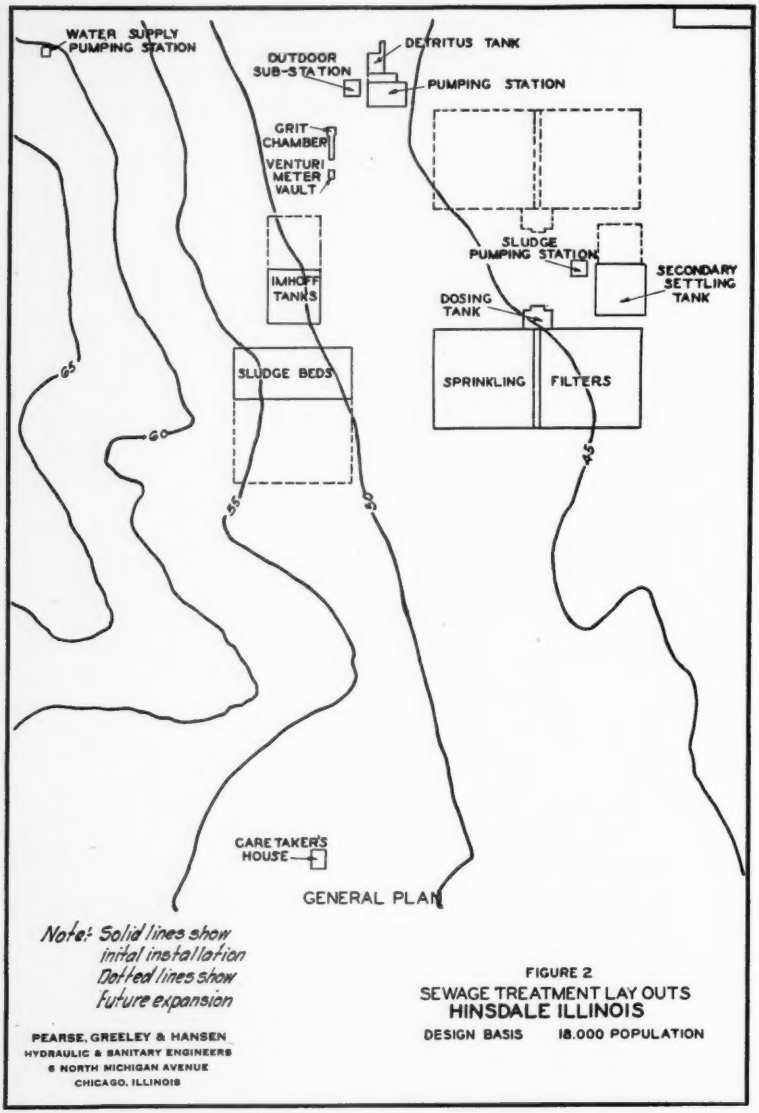
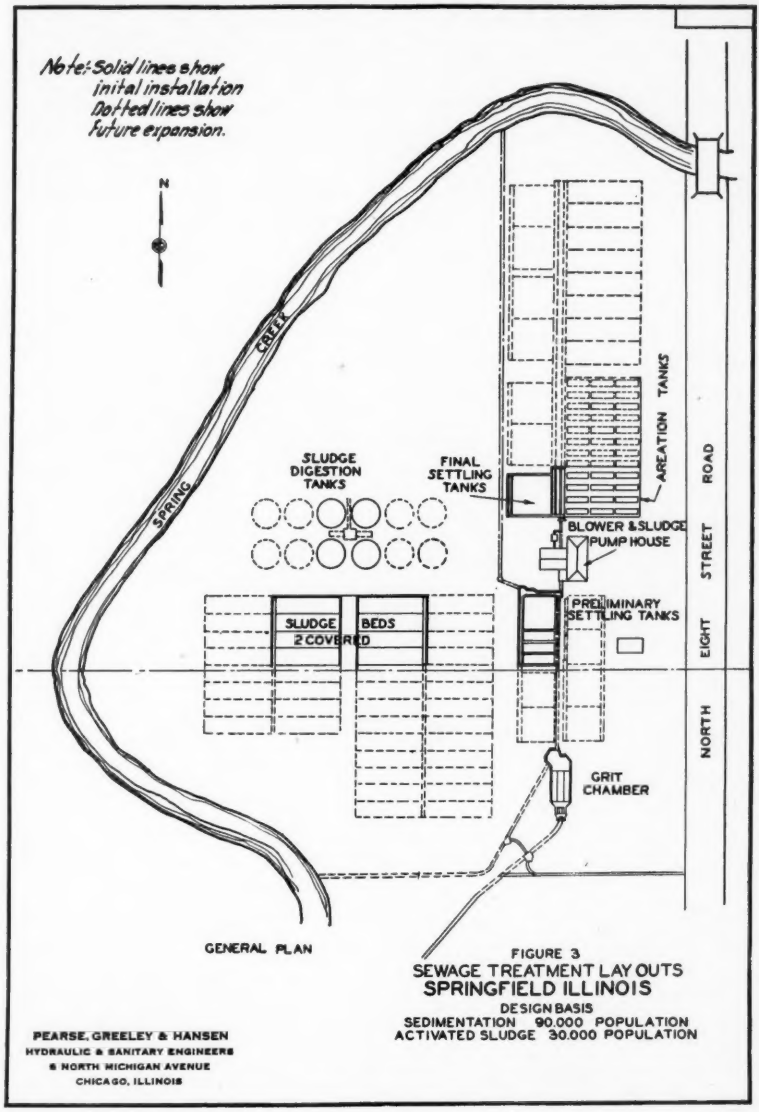


Figure 2 is the installation at Hinsdale. This is a somewhat larger plant than the Centralia plant and represents a compromise between the "centralized" and the "centralized decentralized" general arrangement.



Inasmuch as this plant will probably have to be expanded in the relatively near future and inasmuch as encroaching habitations and suppression of odors may in time become an important factor in the operation of this

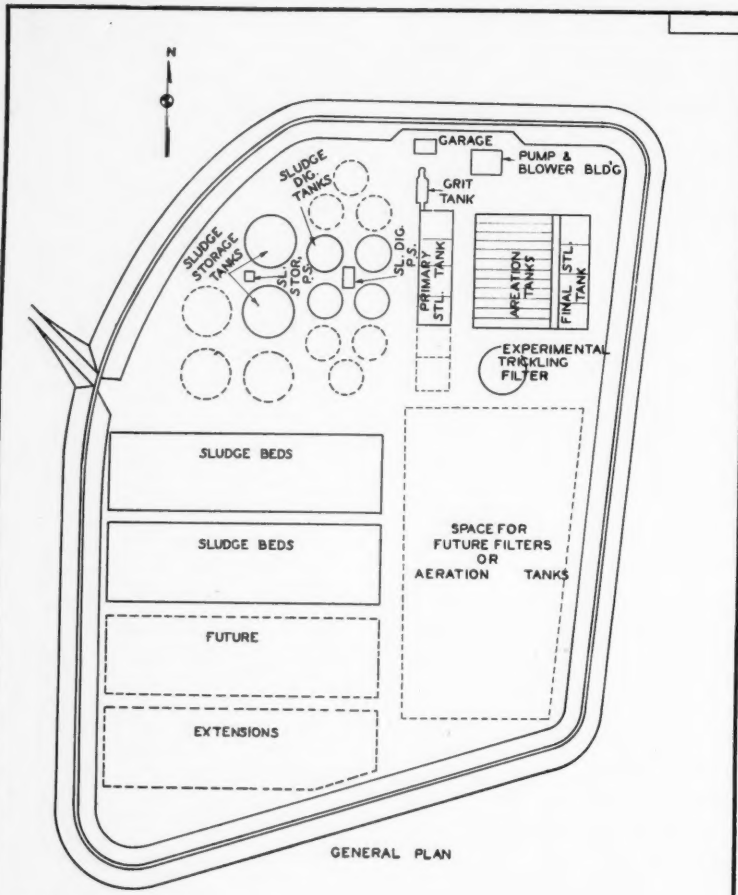


FIGURE 4
SEWAGE TREATMENT LAY OUTS
PEORIA ILLINOIS
DESIGN BASIS =
140,000 POPULATION
PLUS INDUSTRIAL WASTES

plant, it was deemed desirable to leave space and available head for the insertion of the activated sludge process as a preliminary treatment to the trickling filters.

Figure 3 is an installation of the activated-sludge process at Springfield, a plant of medium size for this type of installation. It has some "decentralized" features, but in the main approximates the "centralized" arrangement inasmuch as it is but a relatively few steps from the central building to any of the elements requiring continuous operating control; likewise practically all operations can be readily viewed from the central building which houses pumps, blowers, meters, gas burners and (on the second floor) laboratories and offices.

Figure 4 is a rather large installation of the activated-sludge type, at Peoria, and is more typical of the "centralized decentralized" arrangement than is the plant at Springfield. This installation covers quite a large area and is enclosed by an embankment for keeping out flood water. The arrangement of the plant and available space for future expansion had to be worked out with great care in order to economize as much as practicable on the space to be enclosed by relatively costly embankments.

Summary

By way of summary, the conditions affecting arrangement of sewage treatment plant installations may be enumerated as follows:

1. The horizontal element (arrangement) and the vertical element (hydraulics) must be kept continually in mind.
2. Population growths and changes in character of sewage cannot be accurately predicted, hence ample latitude and flexibility for future expansion must be provided.
3. Provision should be made for the interposition of additional treatment devices where there is any likelihood that these may be needed or may be beneficial.
4. Each element of the works should be so arranged that future extension of that element can be made contiguously to the initial installation for economy and improved operating control.
5. The several elements of a sewage treatment installation should be brought together in a group that will not jeopardize the advantageous expansion of any one element independently of the other elements and which will promote "centralized" control.
6. Small plants generally permit of closely "centralized" control as exemplified by Centralia, Figure 1. Large plants may require "centralized decentralized" control as exemplified by Peoria, Figure 4. Plants of moderate size will require a compromise between the "centralized" and the "centralized decentralized" arrangements.

Making and Interpreting a Sanitary Survey[1]

BY EDWIN C. HURD[2]

A fact-finding investigation and survey, the results of which are presented in statistical and graphical form within the covers of a technical report, is becoming an increasingly popular method of initiating public improvements.

This is particularly true in the field of sewerage and sewage treatment plant construction, probably because of the relative newness of the science and the considerable cost of the projects involved.

Perhaps unfortunately, it is rather seldom that the problem of treating the sewage of a community arises as a result of sanitary idealism, or civic pride on the part of the inhabitants. Quite to the contrary, action is usually precipitated by a State Board of Health or Conservation Department order, or by pressure from the federal government, or litigation threatened by riparian owners or downstream communities, and occasionally by an actual epidemic of typhoid fever or other intestinal disease resulting from the sewage pollution of a source of drinking water.

Because the problem of treating the sewage wastes of a community often arises rather suddenly and must be met without an opportunity for deliberate study and consideration, a technical report prepared by a competent sanitary engineering organization offers many advantages. Until actually confronted with the situation the average citizen and the average city official knows little of the science of sewage treatment, or of the general program of initiating, financing and acquiring a sewage treatment works. Specific information and data are needed for consideration, facts must be uncovered and figures must be developed. It is the purpose of a technical report to supply these essentials.

An investigation and survey treating the subject of a proposed public improvement should first consider the necessity for the improvement. The degree and seriousness of the nuisance in question and the harmful effects resulting therefrom should receive study and the interests of the community in this respect should be carefully weighed. Following the preparation of preliminary cost estimates these costs should be so presented and interpreted that they may be balanced by the taxpayers and officials of the community against the benefits to be derived.

An analysis of various ways and means of effecting the desired improvement is obviously a prerequisite to the development of the design and of cost estimates. Trunk sewer and interceptor locations, various treatment

[1] *Presented at the Third Annual Meeting of the Central States Sewage Works Association, Springfield, Ill., June 10, 1930.*

[2] *Consulting Engineer, Lumber Insurance Building, Indianapolis, Indiana.*

plant sites, various processes of sewage treatment and various types of construction must be investigated. Both construction costs and operating costs must be estimated for all projects and combinations of projects worthy of detailed consideration. And most important of all, in many instances, a study must be made of various possible methods of financing which are applicable to the situation.

The preparation of a preliminary estimate of the cost of a trunk sewer and interceptor system and sewage treatment works must be preceded by the development of the preliminary design of the structures. As a condition precedent to the development of the design, data and information must be available as to the quantity of sewage to be treated, the future growth of the community which must be anticipated, the character of sewage and trade wastes involved and the quality of effluent required. Other factors of decided importance in their influence on the design and construction cost of the proposed project include the areas of the watersheds to be served, the physiography and topography of the terraine to be traversed by trunk sewers and interceptors, the physiography and topography of the proposed plant site and the local cost of labor and materials.

Future Growth of Community.—It is apparent that the future growth of a community must determine to a large extent the capacity for which a sewerage system and sewage treatment plant is designed. This growth in its effect upon design includes increase in area of the sewerage district, increase in density of population, and increase in total population.

The area of the district fortunately is often limited by existing physical conditions and upon studying the topography of the region the engineer finds that nature has relieved him of an otherwise very difficult task. In those cases where natural drainage divides or other limiting features are not present within a reasonable distance from the outskirts of the community the engineer is confronted with the problem of arbitrarily drawing a line on the map with the statement that in his opinion this approximates the line at which the law of diminishing return takes effect and it would be uneconomical to construct sewers at the present time in anticipation of growth beyond this imaginary boundary. It is for problems such as these, where the wasting or saving of thousands and sometimes millions of dollars hinges upon a single technical decision, that it is important for a community to retain the best available engineering talent. The mistakes which have been made in the past have for the most part been in the direction of insufficient size and inadequate design capacity.

Population density assumptions, expressed in the form of a density map, are essential if trunk sewers or interceptors of appreciable length are involved. Density of population is a treacherous subject. Values are constantly changing, and appearances are deceptive. The normal increases in total population, and the increased number of apartment houses, du-

plexes, double houses and hotels, tends to increase the density of population. On the other hand, improved transportation facilities and the resulting migration to the open country is having quite the opposite effect. The density map should be prepared by the field men or by someone intimately acquainted with the community. The total population as computed from the densities and areas shown must of course agree with the estimate of total population.

The facility with which an estimate of total population may be prepared and the accuracy also, it is to be presumed, vary inversely with the proximity of the most recent federal census. There are numerous devices to aid the engineer in his task. The constant arithmetical rate of increase, the uniform percentage rate and averages of the population growth of other cities, serve as yardsticks. When the last census is remote the annual school enumeration, the annual Post Office Department count of carrier stops, the number of employees on the payrolls of principal industries, and the results of census counts made by the local government, local newspapers, or the Chamber of Commerce, may be of assistance. Public utilities sometimes prepare population estimates on their own account, or can furnish data indicating the trend of growth of the community.

As a matter of convenience in subsequent work, after a curve of future population has been drawn, an empirical curvilinear formula may be developed which fits the curve within the limits of the forecast. There is little agreement among authorities as to the form which such an equation should follow. Engineers concur, however, in the opinion that the future population of an individual community cannot be computed arithmetically or estimated by rule-of-thumb methods. Each city presents a separate problem in this respect, and in the last analysis, the prognostication of future growth must depend upon experience and judgment.

Quantity of Sewage.—Of primary importance in the design of trunk sewers and interceptors and of sewage treatment works is an accurate knowledge of the maximum, minimum and average rates of sewage discharge which must be anticipated. The maximum rate of discharge governs the design capacity of sewers, conduits and channels. The minimum rate, together with the minimum velocity requirements, may affect either size or gradient, or both. The average rate of sewage discharge usually establishes the capacity ratings of various treatment plant units.

The quantity of sewage to be anticipated must be estimated on a rational basis by the engineer, but, as in the case of population estimates, depends for its reliability upon skill and experience. A number of criteria are available to guide the engineer in this task, namely, the consumption of water from the public supply and from private and industrial supplies,

the results of sewage discharge measurements and the estimate of future population and population density.

Sewage has been defined as "the spent water supply of a community," and this is true, but the definition must not be taken too literally by the practising engineer. The quantity of sewage may be either greater or less than the pumpage of water from the public supply. Usually it is greater.

Water derived from private industrial supplies and from cisterns and private domestic supplies, as well as from surface run-off and from infiltration, militates in the direction of a greater quantity of sewage. On the other hand it must not be forgotten that water from the public supply which is dissipated in lawn sprinkling, fire-fighting and evaporation, as well as that which is diverted to private cesspools and septic tanks, or wasted direct to streams, does not reach the public sewer system. Leakage from the water distribution system also affects the relationship between water pumpage and sewage discharge, although in many instances such losses have been known to reach the sewers quite directly through open joints.

For these reasons it is obvious that the quantity of sewage will seldom if ever coincide exactly with the pumpage of water from the public supply. There is usually, however, after proper consideration has been given these various factors in the light of local conditions, a close relationship between sewage discharge and water pumpage which cannot be ignored. In nearly all instances the local water consumption is worthy of investigation.

Perhaps the most intangible and elusive factor to be dealt with is the quantitative study of ground water infiltration. The amount of infiltration depends upon the elevation of the water-table, the kind of soil surrounding the pipe, the kind of pipe used, the type and quality of the joints, and the size of the pipe. It may vary from zero to several hundred thousand gallons per mile of pipe. Specifications concerning ground water infiltration are becoming more rigid each year, and the time will probably come when ground water allowances for new construction will be negligible.

Appraising the quantity of infiltration, on the basis of experience in other communities and under various conditions, is hazardous indeed. The safest practice is that of actually measuring the amount by gauging. The discharge of sewage between the hours of 2 a.m. and 4 a.m. in dry weather, may usually be regarded as nearly one hundred per cent ground water, after proper deduction has been made for known quantities of sewage entering the system from industrial sources during these hours.

Gauging of the total quantity of sewage may be carried on either by direct sewer gauging or by the installation of weirs. Direct sewer gauging, translating the readings into sewage discharge units by conventional hydraulic formulas, is quite satisfactory and acceptably accurate where a long straight

section of clean pipe, of uniform gradient and without obstructions is available. This ideal condition is to be found rather seldom, however, and to obtain reliable results it is frequently necessary to install temporary weirs.

A measuring weir may be constructed at the outfall end of a sewer or in a manhole near the outfall. If the flow continues as an open stream, even for a short distance beyond the outfall a conventional stream-gauge type of weir may be used. Where the sewer discharges laterally into a larger stream a weir-box is sometimes necessary at the outfall. The expense of a weir-box or the effects of backwater from the stream may be avoided in many cases by building the weir in an existing manhole, or if necessary constructing a new manhole for the purpose. Considerable care must be used when this method is elected, to assure standard conditions and to avoid inaccuracies due to backwater, improper venting and velocity-of-approach effects. Rectangular, Cippoletti, or V-notch weirs are applicable. It is seldom feasible to avoid end contractions. With proper attention to depth and width of the upstream channel, velocity-of-approach effects may be reduced to two or three per cent or less, in most cases, and may be neglected.

It would be difficult indeed to over-emphasize the importance of making careful determinations and estimates of both present and future rates of sewage discharge. The engineering organization with which the writer is connected was engaged several years ago in the simultaneous preparation of reports for two Indiana cities, both in the 20,000 population class. The public water supplies in both of these cities were practically one hundred per cent metered, the water rates were almost identical, and they both had a water consumption of approximately 80 gallons per capita per day. Ground water conditions were thought to be similar. The field work of the investigation and survey revealed no particular reason for believing that either of these cities would show a greater per capita sewage discharge than the other. The sewers were carefully gauged in both communities. It was found that the sewage discharge in one of these communities averaged 85 gallons per capita per day. In the other city, the sewage discharge averaged 256 gallons per capita per day, or approximately three times as much.

These figures of course represent two extreme examples. The difference apparently was in the soil conditions of the two communities and in the quality of the sewer construction. But this difference would probably not have been revealed until after the construction of the treatment plants had the sewers not been gauged.

If the engineer had arbitrarily assumed, as is sometimes done, a present sewage discharge of, for example, 120 gallons per capita per day, the treatment plant would probably have been constructed in only fifty per cent its

proper size in one instance and would have been fifty per cent too large in the other case. In either event a serious technical error would have been committed and the public's money would have been criminally wasted.

In another Indiana city fourteen weirs were installed in manholes on outfall sewers. Observations were made over a thirty-day period in December and January when the ground was frozen and infiltration was at a minimum. An average dry-weather flow of one and three-quarter million gallons per day was recorded. These weirs were maintained and read throughout the winter. During a corresponding thirty-day period in March and April when, owing to the Spring thaw, the infiltration of ground water was at a maximum, an average total dry-weather flow of two and three-quarter million gallons per day was observed. Thus the excess due to the difference in ground water conditions was more than fifty per cent. Days upon which surface run-off entered the sewer system were excluded from the averages in both cases. The average daily waterworks pumpage was almost identical for the two periods.

Character of Sewage.—The interpretation and practical use of the results of chemical and bacteriological examinations of raw sewage have not kept pace with the development of laboratory methods. It seems likely that a large measure of the significance of laboratory determinations is lost because of the inadequate translation of these data into actual design.

The average sanitary engineer, when he examines a laboratory report, notes whether the sewage in question is strong or weak, and whether it is fresh or stale. He forms some conception of its oxygen requirements, and observes such evidence of trade wastes and other abnormalities as may be apparent. But the best use of the work is restricted by an inadequate scientific knowledge of the relationships which exist. The effect of the results of laboratory determinations upon settling periods, digestion space allowances, aeration periods, filter rates, and the like, is subject to question. It would seem that there is demand for a considerable strengthening of these equations.

A great deal of work along this line has been done in the past and more is being carried on at the present time. Holmes of Syracuse and others have established a rather definite relationship between the suspended solids content of raw sewage and the settling period required for a given removal under standard controlled conditions. Imhoff and some of his contemporaries are computing arithmetically from the results of laboratory analyses predictions of sludge space requirements for digestion. Many operators at the present time attempt to control digestion through the regulation of temperature and pH values. These are mentioned as examples of the sort of knowledge for which there is a great need in the field of sewage treatment. Relationship formulas of a more definite and conclusive character, and covering a wider range of conditions, are required,

Quality of Effluent.—That it is questionable engineering practice and decidedly uneconomical in some cases to design a sewage treatment works without giving proper consideration to the dilution capacity and reaeration effect of the stream or other body of water into which the effluent is to be discharged, has become quite well established in recent years. The present and probable future uses of the body of water require study. Treatment standards and requirements are constantly being raised, and the acceptability of the effluent under anticipated future conditions must be considered.

For an arithmetical evaluation of dilution capacity the engineering profession is indebted to Professor Earle B. Phelps of the United States Public Health Service, who conceived and developed the application of the oxygen balance. Through its use the known oxygen reserves of a stream, with its reoxygenation capacity, may be balanced against the oxygen demand of the raw sewage or treated effluent.

The expression of the results of oxygen demand determinations in terms of pounds per capita per day has become quite popular. As an index of stability and character of sewage, irrespective of dilution, this factor is of value, particularly in making comparisons of sewage from different communities. It is also of service in expressing the concentration and oxygen demand of industrial wastes in terms of equivalent population.

Field Surveying.—The amount of field surveying which is carried on in connection with an investigation and survey is more often limited by the funds available than by the actual requirements of the work. It is an unfortunate fact that consulting engineers frequently agree to perform extensive assignments for totally inadequate fees, and in these instances it is usually the field work which suffers.

In some cases the field work is carried on by the city engineering department, but this arrangement is of doubtful merit. The difficulties of properly coördinating the work and of obtaining the results at the time when they are needed are usually sufficient to offset any possible economic advantages of the plan.

Very few communities in the Middle West are the possessors of a large-scale topographic map of the territory which they cover. Such a map is of inestimable value to the sanitary engineer, particularly in locating watershed divides and in determining tributary drainage areas at various points along the lines of trunk sewers and interceptors, as well as in preliminary studies of the location of the proposed sewers. It is seldom, however, that city officials can be persuaded that the sum expended for a topographic survey will be saved many times over by the almost innumerable uses of the resulting contour map. The engineer is usually forced to content himself with "horseback" methods in the determination of drainage areas, and with cut-and-try surveys in the location of sewers and interceptors.

It seems likely that with the commercial development of stereoscopic methods by which contour maps may be plotted from aerial photographs, with a very limited amount of ground control, the acquisition of large-scale local topographic maps will become more popular. In the present stage of its development the stereoscopic method would appear to offer at least equal accuracy and somewhat superior detail, as well as greatly reducing the time required for preparation. It seems reasonable to believe that production methods which will naturally follow the commercial exploitation of the art will do much to reduce the cost.

Preliminary to the plotting of profiles necessary in the preparation of cost estimates, a level line must of course be run over the location. Invert elevations of sewers to be connected or intercepted are required as well as basement elevations of nearby buildings. If sidehill work is involved, cross-sections are advantageous because they permit minor adjustments of the location in the office and because they facilitate the preparation of accurate estimates. The luxury of a traverse over the location is sometimes dispensed with in the interest of economy, often much to the regret of the engineer after he has been instructed to proceed with plans and specifications.

The office location of the proposed sewage treatment plant on the site requires the use of a topographic map of the land which is available. Such a map is usually prepared by conventional field survey methods. If the work is carried on with sufficient care and accuracy this map should be quite adequate for use in computing excavation quantities for the preliminary estimate of cost.

Unit Costs for Estimating Purposes.—Unit costs of construction vary widely in various localities and from time to time. It is not safe for an engineer to prepare an estimate of cost for work of any appreciable quantity without first making an investigation of local conditions affecting cost.

The possible sources of various materials should be investigated and freight rates obtained. Cement, fine and coarse aggregates, reinforcing steel, structural steel, cast iron pipe, vitrified pipe, and filter media if such are used, should receive attention in this way.

Current wage scales applying to skilled labor of various kinds, as well as the rates being paid for common labor, should also be considered. The "Bid Books" usually kept by local engineers and contractors are sometimes of assistance in the computation or confirmation of unit prices.

Soil conditions and ground water conditions are of utmost importance in any consideration of costs. Excavation in shale or hardpan is much more expensive than in soft earth. Likewise excavation in water-bearing gravel is more costly than in dry soil.

Information and data as to soil conditions and the elevation of the water-table are obtainable through the use of borings or test holes. These

should be made wherever excavation is comtemplated. A hand-operated auger is sometimes sufficient. In other instances it is necessary to use a well-drilling outfit or a core or diamond point drill.

Conclusion

An investigation and survey with a technical report is a rather indefinite form of professional service. It may mean a lot or it may mean a little. Specifications cannot be written to satisfactorily cover the work, although some have attempted to do so. New avenues of approach and unusual situations requiring special attention nearly always present themselves during the preliminary studies. The thoroughness with which the investigation is carried on obviously depends upon the honor and integrity of the engineer handling the work. The personal equation cannot be escaped.

The service includes vastly more than merely "writing a report." The report itself represents but a very small fraction of the effort expended on a properly executed investigation and survey, and is merely a summarized record in permanent and tangible form, of the results of months of field and office work.

The sanitary survey and resulting technical report should be regarded as a part of the comprehensive plan for community development. In any consideration of the subject with which it deals, the report should become the handbook and guide for the engineering department and for city officials. Its recommendations should be adopted by the city plan body, if within their province, and should be incorporated in the improvement platforms of local newspapers and of civic organizations.

The expense of a sanitary investigation is insignificant in the extreme when compared with the total cost of the projects under consideration. Through a superior coördination of the elements of design, and a unification of the comprehensive plan for sewerage and sewage treatment development, the cost of the survey should be justified many times over in the economies which may be effected.

Laboratory Service in Sewage Treatment[1]

BY M. STARR NICHOLS, PH.D.[2]

The laboratory has a well established and justified place in sewage treatment. Engineering features of treatment plant design are based upon or modified by the results of laboratory tests. To Sedgwick, Dunbar, Drown, Calmette, Rideal, Winkler, Chamot, Clark, Phelps and many others we owe a debt of gratitude for their contribution to methods and practice. These workers have made available an indispensable service in sewage treatment.

I wish to discuss the types of laboratory service that can be made available for the control of sewage treatment. It is obviously impracticable to establish a complete laboratory at every treatment plant, yet to operate a sewage treatment plant intelligently, efficiently and economically requires that operation be on a laboratory control basis.

What advantage is it to know the status of operation of our individual plant, whether it be large or small? In most states a plant is required to produce an effluent of specified quality, the degree of treatment depending upon the point of final disposal of the effluent. As citizens of a given community it behooves us to take civic pride in proper treatment of our wastes; and as plant operators our duty is plainly that of doing an intelligent, efficient and economical job of treatment of these wastes.

Visual observation serves as a useful operating control, in the gross, for any plant. Faulty operating procedure may usually be detected by observation, without the benefit of operating results. On the other hand, observation alone will not furnish the proper operating records. A statement made by a plant operator that "our effluent is satisfactory and we get efficient sedimentation," for instance, is open to question, for the personal equation may be operating satisfactorily but not the plant.

To provide the needed laboratory control so that recorded results will speak for the operator and so that an unnecessary burden will not be placed on the small plant, I propose that laboratory service be arbitrarily classified according to the following scheme into four separate divisions.

1. Operator's laboratory.
2. Field control laboratory.
3. Central or state control laboratory.
4. Central or field research laboratory.

Operator's Laboratory.—The operator's laboratory requires either that the operator do his own laboratory work at small plants or that he

[1] *Read at Third Annual Meeting of the Central States Sewage Works Association, Springfield, Ill., June 11, 1930.*

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employ a chemist to do it for him at larger plants. A laboratory for small treatment plants need occupy only a small amount of space, require only simple equipment and consume only a small amount of the operator's time. Two or three Imhoff cones hung up in the sludge-pump room will provide a means for obtaining data on the efficiency of sedimentation or clarification. These results will also furnish a basis for calculations of the rapidity of sludge accumulation, volumes to be digested, and amount of sludge to be shoveled. Cubic centimeters per liter as shown by the Imhoff cone test will equal gallons of sludge per 1000 gallons of sewage; or for an average sewage 3 to 5 gallons of sludge per 1000 gallons of sewage. This is an approximation of the amount of sludge for which we must provide capacity for digestion. To convert this to pounds bone-dry sludge per 1000 gallons of sewage, multiply the number of cubic centimeters of sludge per liter by the factor 0.42. (This bone-dry factor assumes that freshly settled sludge contains 95 per cent moisture.) Further, if we dry this sludge to shoveling consistency we can multiply the cc. per liter by a factor of 2.5 on the basis of approximately 70 per cent moisture, which will give us from 8 to 12 pounds of shovel sludge per 1000 gallons of average sewage. I would recommend that a record be kept only of the volume of liquid sludge as pumped or drawn and digested; and a computed amount of shovel sludge, the latter being the quantity which will be removed from the sludge drying beds. These results compared with actual amount of shovel sludge removed from the beds will give a measure of sludge digestion, and form a basis for calculations of sludge digestion capacity.

If a plant is operating an oxidizing unit following settling tanks, or as a complete unit, a measure of oxidizing efficiency can be roughly obtained by employing the methylene blue stability test, and referring to the stability table as given in Standard Methods of Water Analysis of the American Public Health Association. These two simple tests can be carried out by anyone and furnish much valuable information concerning small plant operation.

For operation of larger plants in which a chemist is employed there are additional tests which can be made to yield results to supplement and amplify those applicable for smaller plants. At the present time, determinations of solids and biochemical oxygen demand seem to be in special favor.

Each type of plant determines the tests which should be applied. Assuming that analytical work in the operator's laboratory is primarily for the purpose of determining the efficiency of operation and that time and money should not be spent in gathering data of questionable value, I wish to summarize and group those tests which I feel give the most information for units of various types. In all plants the best test for

the pollution index of any effluent is the 5-day biochemical oxygen demand. This period of incubation is preferable because the curve of oxygen used flattens considerably after 5 days. Data on dissolved oxygen, nitrites and nitrates also should be obtained on oxidized effluents. Suspended solids yield valuable data on sprinkling filter effluents especially where a secondary settling process or clarification unit is used or contemplated. However, suspended solids on sprinkling filter effluents cannot in any sense be used as a measure of efficiency. For all settling processes suspended solids determinations on the raw sewage and effluent are indispensable. Volatile solids are sometimes advisable on these suspended solids but in general I favor volatile solids on the total solids residue. In this connection I wish to point out that total solids in themselves mean nothing for comparing one sewage or effluent with the total solids from other plants unless corrected for the solids present in the carrying water. In the United States the total solids normally vary from about 40 parts per million in soft water up to as high as 1000 parts per million in some of the deep well waters used by a few cities. In determining the loss on ignition on sewages and effluents I wish to say that the temperature of ignition should be kept rather low at the start and never allowed to pass 600° C. to 800° C., or what is known as a dark red heat.

Bacteriological results are seldom necessary but they yield valuable information at times. Proof that the effluent from a tuberculosis sanitarium contains tubercle bacilli may be sufficient evidence that the effluent should not be discharged into bathing waters.

Bacteriological examination for total count and *B. coli* furnish excellent control means in the chlorination of final effluents. If *B. coli* is used as a measure of efficiency of such chlorination, the completed test should be carried out. A positive presumptive test may be obtained frequently, even though chlorination is effective for most pathogens. The operators of smaller plants will need to depend on the results of analyses and tests made by central or state control laboratories but in the case of chlorination the ortho-tolidin test for residual chlorine will serve admirably in place of bacteriological tests, remembering that an excess of chlorine to the amount of 0.5 part per million after thirty minutes is necessary. Only three test tubes, a color standard and a bottle of ortho-tolidin reagent are necessary for this test.

In the unscrambling of carrying water and waste at all treatment plants, emphasis has always been placed on the character of the fluid portion which is discarded into the waterway, because of the effect on our neighbor's water. If this fluid portion absorbs more than its quota of oxygen, deposits too much solids, has an unsightly appearance, or carries pathogenic bacteria, our neighbor has a right to complain. In most instances the neighbor is the State. The chief business, then, of the

operator's laboratory is to gather and record data which make available in black and white the pollution index of the fluid portion. But the laboratory can do more than guard the plant from the law. It can be aggressive and serve as a clearing house for efficiency in the disposal of the solid portion and devise ways and means of separating water from waste more thoroughly and economically. In this latter capacity it may assume the function of the field research laboratory.

Each sewage treatment plant is a factory necessitated by human existence. The product is clean waterways, sanitary living and a healthful community. Its by-products are sludge for fertilizer, gas for heating our homes and clean, pollution-free effluents for our waterways. It costs less to run an efficient laboratory-controlled factory than it does to run one on the guess basis, and the profits are greater. Because all cities do not believe what I have just said, many of our states maintain sewage treatment inspection service. This brings us to the second division of our laboratory service, the field laboratory.

Field Control Laboratory.—A field laboratory may consist of a set of sampling bottles and test equipment carried in the place of a rumble seat in an automobile, or it may be more advantageously maintained as a mobile sewage testing laboratory. Dissolved oxygen testing equipment should be available in either instance as the state is interested primarily in the effect of the effluent on the waterways. In this connection a trained biologist can obtain valuable data by observing the flora and fauna present in the streams because of the sensitivity and tolerance of the various forms of life to dissolved oxygen. Assistance to operators, rather than state orders, should be the keynote of the methods employed by field laboratory men. Stream flow data, contributory pollution, and influence of larger aquatic vegetation should also form a part of the results gathered by the field laboratory. Composite sampling for field biochemical oxygen demand and central laboratory tests are always necessary. Sewage flow measurements, municipal water pumpage, sludge observations, and a multiplicity of other details devolve upon the routine field laboratory. The best of field equipment will not supply all the facilities required for handling special problems, so it is usually necessary to depend upon the central or state laboratory for additional data to complete the state control inspection work.

State Control Laboratory.—Complete equipment should be provided at the central or state control laboratory to do all routine and special tests. At this laboratory an attempt should be made to do accurate work by most approved methods. The director of this laboratory should systematize the work done in such a manner that the funds available will not be wasted. Cognizance should be taken of the fact that every determination costs a sum of money and that data for control work that

yield no interpretable facts should not be obtained. Unless calculations of capacity and detention time in Imhoff tanks are contemplated, free ammonia and total organic nitrogen should not be determined, for they yield data only for such calculations. Sanitary engineers should so familiarize themselves with the value of all available tests that central laboratories can carry on their work expeditiously and economically.

On account of admixture of various industrial wastes with domestic sewage each sample should be considered a problem in itself. In fact, since industrial waste investigation has become widespread, state central laboratories have found that routine tests become in reality research tests. It is in these encounters that central laboratories have been to some degree converted to research laboratories, the fourth division in our arbitrarily classified laboratory service.

Central or Field Research Laboratory.—The function of the research laboratory may vary from its highly specialized endeavor in field research, in connection with certain mixtures of trade wastes and sewage, to that of the trade waste as a special problem entity. Such a research laboratory was established in Wisconsin under the able direction of Mr. L. F. Warrick, in connection with sulphite liquor waste from the paper industry and industrial wastes from the milk products and pea canning industries.

Every central control laboratory should maintain, if possible, a research branch working on special problems. The work of Theriault and Hommon on the dilution method for determining biochemical oxygen demand and the work of the Milwaukee Sewerage Commission laboratory on dewatering of activated sludge are outstanding examples. There are many live problems which should be attempted. For example: What type of organisms could be used as an inoculum to produce a standard biochemical oxygen demand? Can we improve on the 300 parts per million of sodium bicarbonate used in our standard dilution water? Can we devise a suitable seal to replace the water seal? Should not a definite procedure be instituted for the standardization of our thiosulfate solution? Should the oxygen consumed test be eliminated from our retinue of accepted tests? Much work has been done to show that there are many factors which influence the final oxygen consumed result. Some work done by Mr. Ruf of the Sanitary Engineering Department of the University of Wisconsin shows several variables, some of which seem at present uncontrollable. Is it advisable to try and develop a new method of chemical oxidation as a quick control test for oxidizable organic matter? Turning again to another phase of sewage treatment research, that of sludge digestion, can we find any procedure that will convert the carbohydrate material into more valuable compounds than the combustible gas which is occupying so central a place in this field? The commercial manufacture of higher alcohols from corn mash offers encouragement

for studies of similar application in sludge digestion. While our sewage sludge is usually looked upon as a mass of material to be disposed of as quickly and cheaply as possible, it will always be with us and it offers a substantial quantity of raw material for use if profitable. Aside from the possible profit to be derived from commercial fermentation, is it not possible with suitable enrichment and inoculation to double or treble the volume of combustible gas, as now collected, with a subsequent reduction of solid waste?

Conclusion.—In the laboratory service which I have tried to outline it is seen that each division overlaps the other. My belief is that such should be the case not only with laboratory service but also a similar dependence should be manifest between these laboratories and the actual plant operations. More and more it will become true that every new plant will plan its own laboratory as an integral part, so that sewage treatment will not be recorded altogether on the red side of the city ledger but will be a great municipal industry standing partially, at least, on its own feet.

Coördination in Sewage Disposal.—In a discussion of the paper by H. C. Whitehead, abstracted in this issue, page 625, Arthur J. Martin stated that much money could undoubtedly be saved by concentrating the treatment of the sewage of adjoining areas in a single large works, and where that was impracticable on account of the great cost of the necessary sewers it would often be possible to pipe the sludge from a number of treatment works to a single point. He referred to the pumpage of sludge eighteen miles by the Chicago Sanitary District for digestion at the West Side Treatment Works.

In rural districts there were often ten or a dozen small sewage disposal works, more or less efficiently managed, when it would be easy and economical to place them all under the control of a single capable manager. Too often, however, local jealousy stood in the way. Mr. Whitehead concluded by stating that some of the most difficult sewages to treat were found at small works which received abnormal proportions of trade wastes. Amalgamations of a number of sewages generally produced a sewage subject to lesser variations in flow and strength and consequently tended to simplify the problem of purification.

Operation and Control of Sewage Treatment Plants*

Introduction

The operation of sewage treatment plants is frequently neglected, with the result that the cost of repairs, replacements or damages resulting from improper operation will far exceed the cost of proper operation. A treatment plant is a business proposition in that it represents the investment of a considerable sum of money expended for the purpose of safeguarding the public health and, as such, deserves and requires the careful and conscientious supervision of municipal or other officials. Unless a plant is properly supervised and operated, the purpose for which the plant was constructed will be defeated.

Municipal officials and others responsible for the operation of sewage treatment plants sometimes have the erroneous impression that when a plant has been constructed and placed in operation, the problem is solved and the troubles are ended. Unfortunately such is not the case. Their responsibility for careful supervision and for provision of operating funds continues. Funds should be adequate to secure a competent plant operator and to afford proper care of the plant. It is far better economy to provide sufficient funds regularly than to be compelled to make a large outlay for repairing, rebuilding or even constructing a new plant.

Municipal officials may have been handicapped in the past by a lack of sufficient funds for maintaining and operating sewage treatment plants but under Section 279 of the Village Law and Section 20 of the General City Law a means of obtaining funds for this purpose is provided by the establishment of sewer rents. Such rents may be based upon either the metered consumption of water on premises connected with the sewer system making due allowances for commercial use of water or the number and kind of plumbing fixtures connected with the sewer system or the number of persons served by said sewer system or may be determined by the board of trustees upon any other equitable basis. The funds received from the collection of sewer rents are to be used for the payment of the cost of management, maintenance and operation of the sewer system and sewage treatment works, and may be used for no other purpose.

Inattention or neglect on the part of the plant operator will result in a breakdown or failure of the plant and may even necessitate the rebuilding of units with resulting high cost because of such neglect. For example, if sludge is allowed to accumulate in a tank for too long a period of time, it is likely that the usual means of removal will not be sufficient to with-

* *Reprint of Bulletin Published by Division of Sanitation, New York State Department of Health, C. A. Holmquist, Director. Presented by Charles C. Agar, Asst. San. Engr., before the May, 1930, meeting of the New York State Sewage Works Association at Albany.*

draw it. The detention period in the tank or digestion and gasification will be altered so that a satisfactory tank effluent cannot be obtained. If this effluent is given further treatment on contact beds, on trickling or sand filters, it will usually result in clogging of the filter or contact material so that it is at times necessary either to remove and thoroughly wash the material or completely replace it. This is a very considerable item of expense and sometimes closely approximates the cost of a new installation.

Besides these expenses occasioned by negligent operation, incompetent operation or lack of operation, the municipality or institution is liable for the excessive pollution of water courses into which the effluent is discharged and may be made to pay damages in a law suit resulting from such pollution. Odors are often the result of inefficient operation and may also be the basis of nuisance damage suits.

In view of these facts, this bulletin has been prepared to aid officials responsible for the operation of sewage treatment plants in New York State and to guide the plant operators in the care of their plants.

A daily inspection of each unit of the plant by the plant operator should be made, any unusual conditions recorded, and faulty conditions immediately remedied. The plant operating data should be fully compiled each day, and the record kept, as an aid in maintaining the plant in proper operating condition. Such records are valuable for future reference and as evidence in case of law suits.

It is especially important that the daily flow of sewage reaching the plant be measured and recorded. Methods commonly employed to determine sewage flow are as follows: (1) inches over weir (maximum and minimum, if possible); (2) counters on dosing tanks of known capacity; (3) capacity of pumps and time of operating; (4) meters (Venturi).

The temperature of the air, direction of wind and general weather conditions should be recorded daily. This information is valuable for the investigation of nuisance complaints such as odors.

It is also essential that a few simple tests be made to determine the efficiency of separate units of the plant or as a whole. The results of these tests will: (1) indicate to the operator that the plant is or is not functioning properly; (2) aid the community or institution in case of law suits resulting from alleged pollution or nuisance; (3) assist consulting engineers in planning changes or additions to the plant; (4) enable the officials responsible for the operation of the sewage disposal plant to prepare reports to the public and to the State Department of Health on the operation and efficiency of the plant.

The operator should have for ready reference a blue-print or design of the plant, showing all pipes, valves, gates, etc.

A competent sanitary engineer can materially improve operating

conditions through guidance and advice. It would be advisable for municipal or other officials to retain the designing engineers for a few years to supervise plant operation.

On the following pages are given a few fundamental details of the proper operation of sewage treatment plants. Local conditions may alter somewhat the following operating details but in general this bulletin gives a résumé of the best operating procedure for the various types of treatment described.

Grit Chambers

Grit chambers are usually installed at sewage disposal plants treating sewage from a combined system of sewers, that is, treating both sanitary and storm-water sewage. They may also be installed at plants treating sewage from sanitary sewer systems into which there is a large amount of surface and ground water infiltration. They are also sometimes employed at plants receiving a strictly sanitary sewage.

Purpose.—Their main purpose is to remove heavy suspended matter, grit, coal, etc., from the sewage by settling. This is accomplished by providing a compartment of a size sufficient to reduce the velocity of the sewage flow to approximately one foot per second. This removal of the heavy suspended material tends to prevent: (1) unnecessary wear on pumps and fine screens; (2) accumulation of grit and clogging of valves; (3) accumulation and clogging at the base of sludge pipes, in inverted siphons and in small channels at the plant.

Operation.—1. Grit chambers should be cleaned after every large storm.

(2) The depth of grit throughout the length of the channel should be determined frequently by means of a graduated pole with a small board or other flat surface on the end. During dry weather periods, this should be done at least every 10 days.

(3) Grit chambers should be cleaned whenever tests show that the grit compartment (the compartment below the inverts of entering and outlet channels) is filled with hard material to 50 or 60 per cent of its capacity.

(4) The grit should be promptly disposed of by burying it or drying it on sludge beds. If it is sufficiently clean, it may be used for filling in low land.

Operating Record.—(1) Dates of cleaning; (2) Cubic feet of grit removed; (3) Method of disposal of grit.

Coarse Screens ($^1/_2$″–3″ Openings)

Purpose.—The protection of pumps by the removal of large floating objects, rags, sticks, etc.

This removal also tends to prevent clogging of pipe lines, Imhoff slots, valves and small channels in the plant.

Operation.—(1) Remove the screenings daily or oftener if necessary to prevent clogging of the screen and consequent backing up of sewage in the outfall sewer.

(2) Promptly dispose of screenings by: (*a*) Burial, covering by at least 6 inches of earth, either by ploughing under the soil or shallow trenching. In the winter they may be placed in trenches, treated with chloride of lime or other disinfectant and covered with earth as early in the spring as possible; (*b*) Incineration, after draining.

(3) Clean the screen chamber, removing all accumulated sludge and grease, at least once a week.

Operating Record.—(1) Cubic feet of screenings removed daily; (2) Method of disposal of screenings; (3) Dates of cleaning screen chamber.

Fine Screens ($^1/_2$" or Less)

Purpose.—To remove part of the suspended solids, as well as coarse material, thereby relieving the load on subsequent treatment units.

Operation.—(1) Fine screens are usually continuously mechanically cleaned, either by water, air or revolving brushes, and therefore all moving parts should be adequately oiled or greased to keep them in proper working condition.

(2) Remove and dispose of screenings promptly by: (*a*) mixing with garbage and incinerating; (*b*) dewatering by pressing, and then burning or burying the solids; (*c*) burial, covering by at least 6 inches of earth, either by ploughing under the soil or shallow trenching. In the winter, they may be placed in trenches, treated with chloride of lime or other disinfectant and covered with earth as early as possible in the spring.

Operating Record.—(1) Number of units in service; (2) Cubic feet of screenings removed daily; (3) Method of disposal of screenings; (4) Daily power consumption. (Kilowatt hours.)

Sedimentation Tanks and Septic Tanks

Purpose.—(1) To remove from the sewage by settling, a large part of the suspended solids; (2) to digest or liquefy a part of these settled solids.

Operation.—(1) Sludge and scum should be removed whenever they accumulate to a combined depth equal to $^1/_4$ the depth of the tank below the flow line.

(2) Sludge should be removed when large suspended particles are observed in the effluent, or when the daily test of settleable solids in the Imhoff cones shows any appreciable increase of settleable solids in the effluent.

(3) All inlet and outlet channels, pipes, weirs, valves, etc., should be kept clean and free from accumulations of grease and grit.

(4) Where more than one sedimentation tank unit is available, it is sometimes advisable to remove or "cut out" one unit from service for a period ranging from one to two months in order to allow digestion of the accumulated solids.

Operating Record.—(1) Settleable solids in raw sewage and effluent as determined by Imhoff cones daily.

(2) Drawing of sludge: (*a*) dates; (*b*) cubic feet of sludge removed as determined by the depth of the wet sludge on the sludge bed, or the reduction of the depth in the settling tank.

(3) Scum removal: (*a*) dates; (*b*) cubic feet of scum removed.

Mechanically Cleaned and Plain Settling Tanks with Separate Sludge Digestion

Purpose.—(1) To remove a large part of the suspended solids by settling without intended anaerobic or septic decomposition in the settling tank; (2) To decompose, liquefy or gasify in separate sludge digestion tanks the solids transferred to them from the plain settling tanks.

Operation.—(*A*) *Plain Settling Tanks.* (1) The settled solids or sludge should be completely removed at frequent intervals, at least daily, from the settling tanks to the separate sludge digestion tanks. Mechanical equipment installed for the collection of the sludge in the settling tanks should be operated continuously or at least twice a day, depending upon local conditions.

(2) Septic action in the plain settling tanks as evidenced by "gassing" or an appreciable increase of the settleable solids in the settling tank effluent should be avoided by prompt and regular removal of sludge to the sludge digestion tanks.

(3) Grease and scum should be removed daily using perforated skimmer (see Plate I) and the tanks should be maintained in a clean condition at all times.

(*B*) *Separate Sludge Digestion Tanks.* (1) The contents of the tank should be stirred or agitated at frequent intervals by mechanical or other means to afford more rapid and efficient digestion and to lessen the possibility of "foaming."

(2) Where heating coils or other means of heating the contents are available, the temperature should be maintained at about 80° F. or above.

(3) The amount of raw sludge added daily should not be over one-twentieth the amount of "ripe" sludge in the tank, on the basis of the dry solid content.

(4) When unusual conditions, such as "foaming," "acid" sludge, etc., develop, if the operator is not experienced in handling such con-

ditions, an experienced sanitary engineer should be called in and his recommendations followed.

(5) Care must be used in removing digested sludge to avoid the removal of such a large amount that the ratio of "ripe" sludge to raw sludge added drops below twenty to one.

(6) The reaction of the sludge should be maintained at a hydrogen-ion concentration of 7.2–7.6. The addition of lime to the sludge will increase the hydrogen-ion concentration. Satisfactory results are sometimes obtained with slightly lower values.

Operating Record.—(1) Settleable solids in raw sewage and settling tank effluent as determined by Imhoff cones daily.

(2) Cubic feet of sludge removed to digestion tanks daily.

(3) Occasional determination of dry solids in sludge removed from settling tank to digestion tank.

(4) Removal of sludge from digestion tank: (*a*) dates; (*b*) cubic feet of sludge drawn as determined by the depth of wet sludge on the sludge bed or the reduction in depth in the digestion rank; (*c*) percentage of dry solids in sludge drawn.

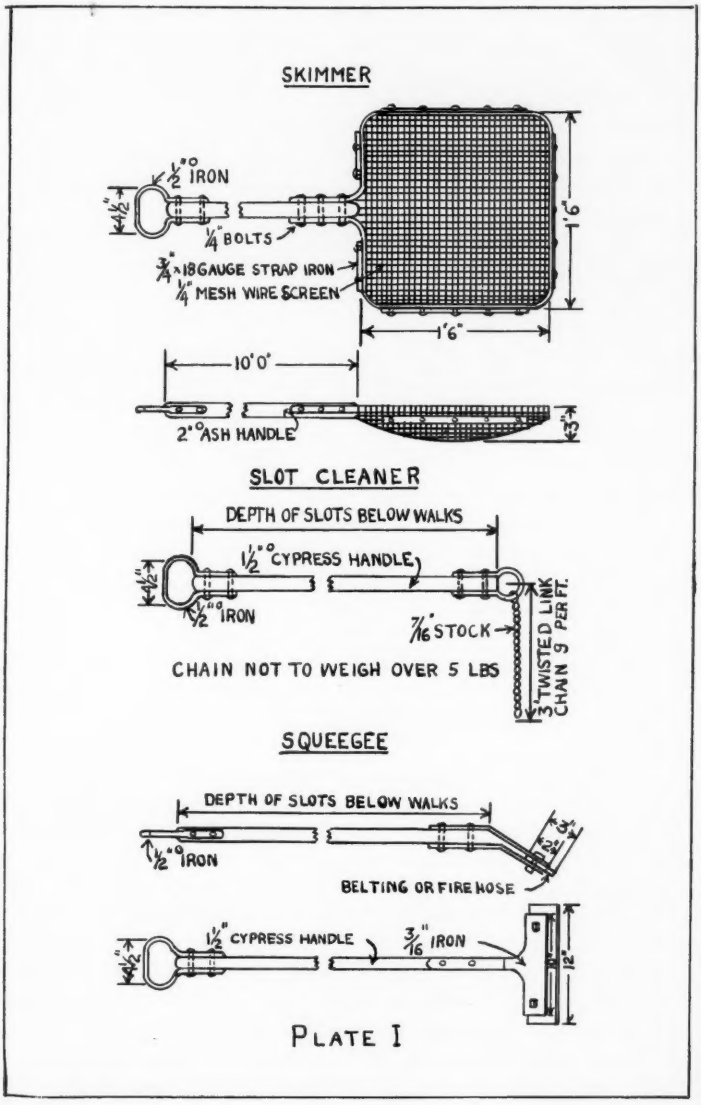
(5) Where possible, the hydrogen-ion concentration of the sludge removed from the settling tank and in the digestion tank should be determined and recorded.

Imhoff Tanks

Purpose.—(1) To remove the settleable suspended solids in the sedimentation compartment; (2) to liquefy, gasify and digest the settleable solids in the sludge compartment by bacterial action.

Construction and Function.—To accomplish the above purposes, the Imhoff tank is designed and built as a two-story structure, the upper or settling compartment serving for sedimentation and the lower or sludge compartment for bacterial digestion. A trapped slot between these compartments provides a means for the solids settled out of the sewage in the upper chamber to pass into the lower or sludge digestion compartment. This trapped slot also prevents the gases, resulting from decomposition in the digestion compartment, together with gas-laden particles of sludge, from entering the settling compartment and from coming in contact with the settling sewage. These gases and gas-laden particles are deflected by the sloping bottom of the sedimentation compartment and rise in the scum chamber or gas vent where the gases escape and a large part of the previously gas-laden particles settles again. In a properly working tank, the gases given off should be inoffensive with a slightly tarry or gassy odor.

Cleanliness is one of the fundamentals of a successfully operated plant.



All accumulations of grease, grit and refuse matter should be promptly removed and properly disposed of.

Operation.—*1. Sedimentation Compartment.* (*a*) Grease and scum

in the sedimentation compartment should be removed daily. This is best accomplished by the use of a dish-shaped perforated skimmer (see Plate I). Such grease and scum should be promptly disposed of by burying or burning. Where objectionable conditions are not likely to develop, the grease and scum may be placed in the gas vents.

(*b*) The sides and slopes of the sedimentation compartment should be carefully scraped with a rubber squeegee (see Plate I) and all solids pushed down through the slots at least every week.

(*c*) The slot in the bottom of the sedimentation compartment must be kept open and free from obstruction of any kind. Every other day the slot should be cleaned by the use of a chain drag (see Plate I), taking care to traverse the entire length of the slot.

(*d*) Failure to follow carefully the foregoing operating procedure will usually result in clogging of the nozzles of a trickling filter bed, if one is used, and a deposition of solid matter on or in such filter, due to grease, scum or sludge being carried through the tank into the effluent.

(*e*) Where the design of the tank will permit, the direction of flow should be reversed in the sedimentation compartment at least once a month, in order to distribute the solids in the digestion chamber.

2. *Gas Vents or Scum Compartment.* The scum in the gas vent should be thoroughly broken up at least weekly to afford an easy escape for the gas from the digestion or sludge compartment. This may be accomplished by:

(1) Breaking the scum up with a hoe, rake or other suitable tool.

(2) Hosing the scum in the gas vents with water under pressure.

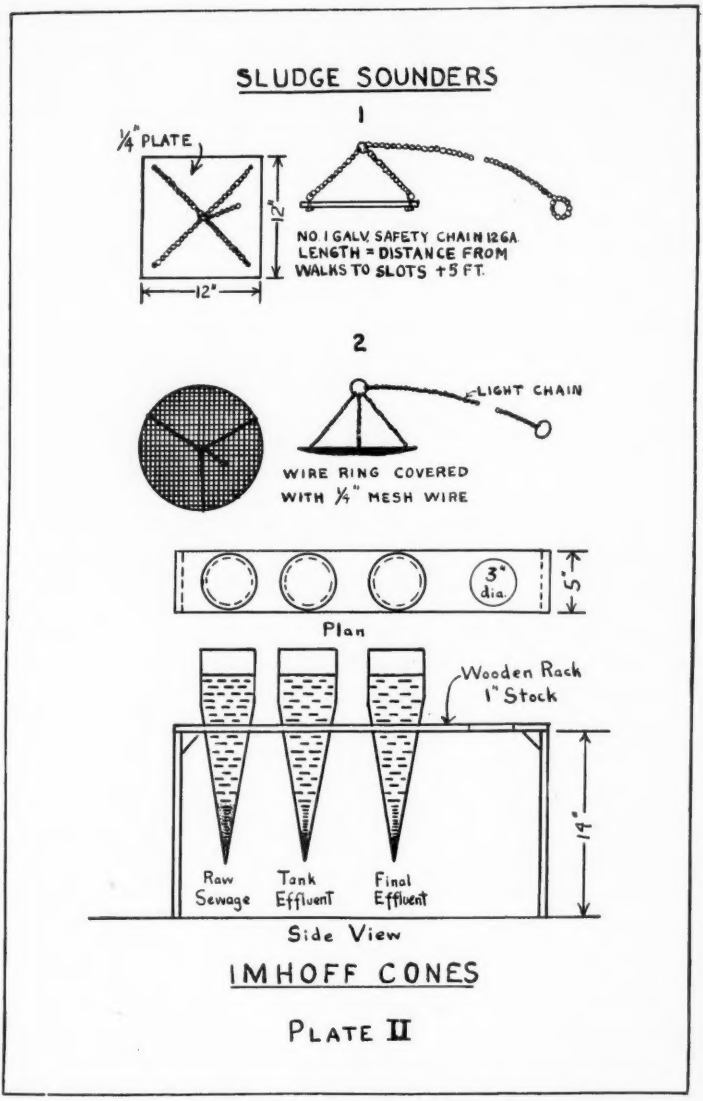
(3) Keeping the scum in the gas vents saturated with sewage from the sedimentation compartment, or preferably liquor from the digestion compartment, by using a small portable pump or air lift device.

(4) Punching holes through the scum at two-foot intervals with a wooden pole, 3 inches in diameter and 8–10 feet long.

(5) The scum may be removed and dried in a sludge drying bed if its depth approaches 2 to 3 feet.

3. *Sludge Compartment.* (*a*) The height of the sludge in the sludge compartment should be determined at inlet and outlet ends of the tank at least once a month. The use of a pump for this purpose is the most desirable and satisfactory. The use of the plate or disk method is not recommended, except for the final settling tanks. The following are suitable methods for measuring the depth of sludge:

(1) One method involves the use of a pitcher pump provided with a rubber suction hose, weighted on the end and the length marked on the hose at intervals of two feet, measuring from the weighted end toward the pump. The hose is gradually lowered through the slot in the sedimentation compartment, meanwhile constantly pumping, and the length of immersed hose, when sludge first comes through the pump is determined. When sludge is encountered, the pump will usually "choke" before sludge appears.



(2) A pitcher pump may also be used with a rubber suction hose, weighted on the end by a 4-foot length of steel pipe as an integral part of the pump suction line. This suction hose may be graduated and marked as above and the determination of sludge

depth made in the same manner except that the hose is lowered through the gas vent instead of the sedimentation compartment slot.

(3) The sludge depth may also be determined by use of an iron plate or weighted wooden block, about 12-18 inches square, attached to a wire or chain (see Plate II) lowered through the gas vent. The plate or block will stop when the sludge is reached and the distance from the surface to the sludge level is determined by the graduated wire or chain by which the device is lowered.

(4) Where the condition of gas vents will permit the use of a lighter implement, a modification of the above may be used. This consists of a wire loop, 12 or 15 inches in diameter, covered with a disk of quarter inch mesh wire. A very light chain should be used with this disk suspended at three points. (See Plate II.)

(*b*) Sludge should removed:

(1) Whenever the sludge depth approaches within 18 inches of the slot in the sedimentation compartment. (2) In small amounts at frequent intervals rather than in large amounts at longer intervals. Usually some sludge should be drawn every month.

(*c*) Sludge should be removed at a slow regular rate to avoid the formation of a channel through the sludge in the sludge compartment and the withdrawing of partially digested sludge or the liquid above the sludge.

(*d*) If sludge does not flow readily, it may be started by:

(1) Agitating with water under pressure through perforated water pipes in the bottom of the sludge compartment, if such pipes are available. (2) Applying water pressure through hose immersed into the sludge compartment or through the sludge riser pipe. (3) Agitating around sludge inlet with long rods through the sludge riser pipe.

(*e*) After use the sludge pipes should be flushed out and refilled with water or sewage to prevent the sludge from hardening and clogging the sludge pipes.

Operating Record. (1) Numbers of tanks in service daily.

(2) Settleable solids in raw sewage and tank effluent as determined by Imhoff cones daily.

(3) Removal of sludge: (*a*) dates; (*b*) cubic feet of sludge drawn as determined by the depth of the wet sludge on the sludge bed or the reduction in the depth in the settling tank; (*c*) per cent of dry solids in sludge drawn.

(4) Suspended solids in raw sewage and tank effluent by Gooch crucible method where possible.

Foaming in Imhoff Tanks

"Foaming" is a term used to describe the condition which develops sometimes in Imhoff tanks, whereby gas, froth and scum rise in the scum compartment or gas vent and carry over the wall into the sedimentation compartment. Besides being unsightly and disagreeable, this condition

seriously interferes with the efficiency of the plant. Dark scum and solid material may be carried into the sedimentation compartment and be discharged in the tank effluent. This will cause an unsatisfactory tank effluent and an abnormal load on subsequent treatment units.

When foaming occurs, it is frequently advisable to seek the advice of an experienced sanitary engineer.

However, there are a few simple treatments which may under certain conditions remedy or improve the condition.

(1) Relief may sometimes be obtained by drawing some sludge.

(2) Hosing the gas vent area with water under pressure will sometimes help.

(3) Cutting the tank out of service if possible and allowing it to rest will sometimes improve the condition.

(4) Paddling the foam with long-handled hoes is also temporarily effective.

(5) Hydrated lime will sometimes correct a foaming condition.

(6) The treatment of the raw sewage with chlorine at rates of 3 to 5 p. p. m. will often lessen foaming.

Dosing Apparatus

Purpose.—To provide periodic and uniform distribution of the sewage on the filters or other subsequent units.

Operation.—(1) The mechanical equipment should be kept in perfect working order. Moving parts should be regularly oiled or greased.

(2) Pipes and air lines should be kept open and free from obstructions and accumulations of any sort.

(3) Any mechanical breakdown should be repaired immediately.

(4) Where there are two units or where it is possible to cut out a unit without seriously interfering with subsequent treatment, a complete cleaning of the dosing tank should be made weekly, removing all grit and sludge deposited, and removing all growths and deposits on pipes and walls. This is necessary in order to prevent clogging of the nozzles in a trickling filter unit. In the event that it is not feasible to cut out a unit, the walls and pipes should be cleaned as carefully as possible by means of an inverted scraper taking care that solid material does not enter the dosing tank outlet.

Operating Record.—(1) Readings of the automatic dose counters at the same hours every day. (2) Dates of cleaning.

Trickling or Sprinkling Filters

Purpose.—To stabilize or oxidize, with the aid of bacterial action, the organic matter and to remove the solids which have not been removed by the previous treatment.

Operation.—(1) The nozzles should be inspected daily. All clogged nozzles should be cleaned and any broken nozzles replaced. Especially careful attention is required in winter to prevent freezing.

(2) The surface of the filter bed should be kept free from vegetable growths.

(3) The formation of ponds or "pooling" on the surface of the filter bed may be remedied or prevented by: (*a*) flushing the surface of the filter with a fire-hose; (*b*) raking or forking the surface of the filter bed; (*c*) punching holes through the top layer of the filter medium with iron bars; (*d*) heavy applications of chlorine or chlorinated lime for short periods applied weekly to the filter bed influent at the dosing tanks; (*e*) operation of units may sometimes be improved by putting them out of service occasionally for a period of 12–48 hours except during cold weather.

(4) Where the design of the filter bed will permit, the presence of large numbers of filter flies may be controlled by periodic flooding of the filter beds or sometimes heavy doses of chlorine in the sewage applied to the beds.

(5) The distribution piping should be flushed periodically.

(6) The underdrains should be flushed out occasionally with water hose or other suitable flushing devices, if the filters are so constructed as to make this possible.

Operating Record.—(1) Filter bed units in service daily; (2) Filter bed units out of service; (3) Number of nozzles cleaned daily; (4) Putrescibility of the filter effluent as determined by the Methylene Blue Test twice each week; (5) Settleable solids in filter bed effluents as determined by Imhoff cones daily.

Contact Beds

Purpose.—To stabilize or oxidize, with the aid of bacterial action, the organic matter and to remove the solids which have not been removed by the previous treatment.

Operation.—(1) The surface of the beds should be kept free from solids and vegetable growths.

(2) The dosing apparatus must be kept in perfect working order to prevent freezing and to insure proper control and operation of the beds.

(3) Resting of a contact bed unit for a period of 12–48 hours will sometimes improve its operation.

(4) When the beds clog so that satisfactory results or removal of organic matter cannot be obtained, the contact material must be removed and cleaned or replaced.

Operating Record.—(1) Contact bed units in service daily; (2) Contact bed units out of service; (3) Total number of fillings per day; (4) Putrescibility of the contact bed effluent as determined by the Methyl-

ene Blue Test twice each week; (5) Settleable solids in the effluent as determined by Imhoff cones daily.

Secondary or Final Settling Tanks

Purpose.—To remove the settleable suspended solids which are present in the effluents from the sprinkling filter or the contact bed units.

Operation.—(1) The sludge should be removed frequently to prevent gasification of the solids which results in discharge of solids with the final effluent.

(2) The depth of the sludge should be determined at frequent intervals by the use of a sludge sounder (see Plate II) or other device. Sludge should be drawn whenever the detention period is reduced to less than 1 hour or when there is an appreciable increase in the settleable solids in the effluent.

(3) The sludge is disposed of in the same manner as sludge from primary settling tanks, *i. e.*, dried on sludge drying beds, or it may be pumped into the primary settling tanks.

Operating Record.—(1) Number of units in service daily.

(2) Removal of sludge: (*a*) dates; (*b*) cubic feet of sludge removed as determined by the depth of wet sludge on the sludge bed or the reduction in depth in the settling tank.

(3) Putrescibility of the final effluent as determined by the Methylene Blue Test twice each week.

(4) Settleable solids in the effluent as determined by the Imhoff cones daily.

Sludge Drying Beds

Purpose.—To reduce water content of the sludge so that it may be readily handled.

Operation.—(1) Sludge beds should not be filled to a depth of over 12″ or to such a depth that the sludge cake cannot be removed within two weeks in good drying weather.

(2) If drying is slow because of clogged beds, a thin layer of material (usually sand) at the surface of the drying bed should be removed and replaced with clean material.

(3) The surface of the drying bed should be kept clean and free from all previously discharged sludge. *Never discharge wet sludge on partially dried sludge.*

(4) The surface of the sludge drying beds should be kept level to afford an even distribution of sludge over the surface of the bed.

(5) Remove the sludge just as soon as it may be handled with a fork.

(6) Dried sludge may be used for fill, buried or spread upon the ground, where it will not be carried into a stream or watercourse by rain.

(7) In many communities, the sludge is readily disposed of by giving or selling it to nearby farmers for use as fertilizer. This should be encouraged as sewage sludge has been found to have considerable fertilizing value. It is especially suitable for grassland and orchards. It has likewise been successfully used for golf greens and fairways. It is not advisable, however, to use it for the fertilization of crops which are served at the table in an uncooked condition.

Operating Record.—(1) Sludge drawn to the beds: (*a*) Dates and bed numbers; (*b*) Depth of wet sludge on bed; (*c*) Cubic feet of wet sludge.

(2) Sludge removed from the beds: (*a*) dates and bed numbers; (*b*) depth of dry sludge; (*c*) cubic feet of dry sludge; (*d*) time required for drying; (*e*) weather conditions during drying.

(3) Method of the disposal of dried sludge.

(4) Where possible the solid content and hydrogen-ion concentration of the wet sludge, and the moisture in the dry sludge removed should be determined and added to the above record.

Sand Filters

Purpose.—To obtain by bacterial action and mechanical filtration a high degree of purification of a sewage, usually after preliminary treatment.

Operation.—(1) The beds should not be used continuously but sufficient time should be allowed between doses for the bed to drain thoroughly and "rest" between applications. Satisfactory operation of a filter bed depends on the presence of oxygen in the bed and therefore opportunity for the entrance of air into the bed must be provided by the "rest" periods.

(2) The beds should be periodically cut out of service, allowed to dry and the surface raked or scraped clean.

(3) "Pooling" should not be allowed to develop on the beds as this tends to produce septic action and obnoxious odors. Pooling indicates that cleaning is necessary.

(4) The surface of the beds should be kept level to afford uniform distribution of the sewage.

(5) Weeds, grass, etc., should not be allowed to grow on the beds.

(6) For winter use, the open air beds should be ridged every 2 feet in order to hold the ice off the main body of sand. An alternate method is that of raking up small 4 to 6 inch piles of the top surface every 3 feet over the surface of the bed. The bed should be cleaned and leveled as early as possible in the spring.

(7) The depth of the bed should be maintained by removing during cleaning only the least possible amount of sand ($^1/_4$–$^1/_2$ inch). Once

a year clean sand should be added to replace that removed during the year.

Operating Record.—(1) Numbers of beds used daily.

(2) Quantity of sewage applied daily.

(3) Numbers of beds out of service or drying daily.

(4) Putrescibility of final effluent as determined by the Methylene Blue test twice each week.

(5) Cleaning of beds: (*a*) number of beds; (*b*) dates of cleaning; (*c*) amount of material removed.

Disinfection of Sewage Effluent with Chlorine

Purpose.—To prevent bacterial contamination of streams or other bodies of water, used for water supplies, shell-fish growing, or bathing.

The effective chlorination of sewage or sewage effluents depends upon the presence of adequate quantities of chlorine in all portions of the sewage for sufficient time to provide the necessary period of contact between the disinfectant and the bacteria. Any interruption in the chlorination process will be followed at once by the delivery of unchlorinated sewage, even though other portions of the sewage may have been properly disinfected previously. When chlorine is added to sewage, it reacts with the organic matter in the sewage and is absorbed. The rate of this absorption depends upon the temperature of the sewage, the amount of organic matter, and the dose of chlorine. The first of these factors cannot be controlled, so the net result has to be ascertained by tests for residual chlorine in the sewage, which will indicate whether the chlorine rate should be increased or decreased.

Residual chlorine in sewage will react with a prepared solution of orthotolidine to form a yellow color, the intensity of which is proportional to the amount of residual chlorine in the sewage. In making this test the intensity of the color is compared with standard colored solutions, which are prepared to match the colors produced by graded amounts of residual chlorine. The turbidity of the sewage is compensated for by placing a bottle of the sewage in front of the standard colored solution.

It is also possible to use standard colored glass discs in place of the standard color solutions in some types of comparators.

Experience has shown that most sewages can be effectively chlorinated when sufficient chlorine is added to provide a residual chlorine concentration of at least 0.5 p. p. m. 15 minutes after the chlorine is introduced into the sewage. Thus the dose of chlorine is varied in accordance with the rate of absorption of the disinfectant as indicated by the amount of residual chlorine remaining at the end of the 15-minute contact period.

The strength of any sewage varies greatly with seasonal changes, with the days of the week, and during the hours of the day. The amount

of chlorine required varies accordingly. Unless it is possible to make frequent tests regularly throughout each day, a series of tests should be made to determine what time of the day the most concentrated and heaviest doses of sewage reach the point of chlorination and tests should be made thereafter at that time each day. This occurs at most plants some time during the forenoon. It may be practical to readjust the chlorine dosage for the less concentrated night sewage providing that the adjustment is based on a residual chlorine test made at the time of greatest chlorine demand for the period for which the chlorinator is set. It is unwise to attempt to adjust chlorine dosage too closely as chlorine is relatively cheap and an overdose will seldom do any harm.

Operation.—(1) Chlorine should be applied in such quantity that there will be a residual of at least 0.5 p. p. m. as determined by the orthotolidine test after 15 minutes contact of chlorine with the sewage effluent.

(2) The test for residual chlorine should always be made at the time when the sewage effluent is the strongest or when it requires the largest amount of chlorine for treatment.

(3) Weigh chlorine tank each day at the same time to determine the amount of chlorine used.

(4) The chlorine must be applied *continuously* in the proper quantities.

(5) Before connecting a new chlorine cylinder to the control apparatus, blow off some of the chlorine from the new cylinder into the air in order to prevent clogging of the apparatus.

(6) Examine the chlorine apparatus daily and if any trouble is found which cannot be corrected by the operator notify the manufacturer a once.

(7) It is not advisable to draw more than 40 lbs. of chlorine from any one cylinder in a 24-hour period because of the danger of "freezing" and slowing up the chlorine flow. If more chlorine is necessary, two or more tanks should be connected and used in parallel.

(8) The operator should always have on hand a stock of the usual replaceable parts for the chlorine apparatus and an extra supply of chlorine tanks.

(9) Leaks in the chlorine apparatus may be detected by the formation of white fumes when tested in the immediate vicinity with the vapors from an ammonia solution. (Household ammonia is satisfactory.)

Operating Record.—(1) Volume of sewage treated daily; (2) Rates of application of chlorine daily; (3) Weights of chlorine tanks at start and end of 24-hour period; (4) Date of connecting new cylinders and their weight; (5) Daily determinations of residual chlorine by orthotolidine test.

Editorial

A Few Kind Words

Amid the voluminous literature extolling the superior virtue of separate digestion it is consoling to find now and then a few kind words for our old friend, the Imhoff tank. For the past decade the Imhoff tank has had mostly harsh words concerning the evils of foaming, odors and other impedimenta of incomplete digestion. But one may ask whether such widespread damnation is not due partly to the well-known swing of sentiment from one extreme to the opposite. Imhoff tanks were hailed as a great advance in sewage treatment in the 1910–1920 decade, but in the 1920–1930 decade separate digestion has had the spotlight of publicity, and rightly so, but in our newly-awakened interest in heating, gas collection, thermophilic digestion and pH control we should remember that Imhoff tanks are still treating the bulk of the sewage that is treated in this country, and that the objectionable features that have been emphasized so emphatically are due, usually, to insufficient capacity, the presence of industrial wastes, or inadequate operating control.

One of the major complaints against Imhoff tanks is the presence of uncontrollable foam and scum in the gas vents. It is difficult to obtain accurate information on this subject, but occasionally we do obtain facts. The paper by Dr. Imhoff in this issue contains facts concerning scum in some twenty-seven Imhoff tanks in the Ruhr District. A study of his data is of interest. He states that during the initial period of operation of digestion tanks, foaming may occur both in Imhoff and separate digestion tanks. In the Imhoff tanks of the Ruhr District this occurred, however, only at Hagen. "Foaming reappeared after the tanks were emptied by faulty operation and had to repass through the ripening period, and later again when the tanks were overloaded with sludge."

These comments summarize the three main factors tending toward foaming: (1) no ripe sludge during initial operation, (2) discharge of too much ripe sludge and (3) overloading the sludge compartment until sludge extends above the slots. Underseeding and overloading are dependent upon operating control, assuming the digestion capacity is adequate. Inadequate operating control may therefore account for many reports of foaming tanks. Nearly all Imhoff operators have had occasional epidemics of foaming in tanks which normally behave quite acceptably. We may expect similar difficulties in separate digestion.

although in such cases the operator has the benefit of heat, mechanisms and circulation for combating the tendency toward foaming.

Scum formation is apparently not a serious difficulty in Germany. Likewise in the United States scum formation in Imhoff tanks has not appeared to be a major difficulty. A recent questionnaire study by a committee of the American Public Health Association brought replies from the operators of twenty Imhoff plants and twenty-one recently installed separate digestion plants. In general, operators of heated separate digestion tanks reported little difficulty from scum, while operators of several Imhoff tanks reported scum was bothersome. The Imhoff tank operators suggested, however, that the difficulty was due largely to lack of facilities for drawing off scum, or to insufficient screening or skimming of the sewage. With more attention being paid to facilities for withdrawing scum and with the increasing use of skimming tanks, circulation of sludge liquor and more intelligent control, may we not expect decreasing difficulties from scum in Imhoff tanks? Notwithstanding such improved design and operation, however, Imhoff tanks will occasionally operate "upside down," and tax any facilities or operating skill to the limit before relief is afforded. Such abnormalities may also occur in separate digestion tanks. Is it not advisable for the present to await further developments and to retain a little faith in, hope for and charity toward the Imhoff tank?

Ave atque Vale

In this issue we hail an old comrade, Professor Earle B. Phelps, and bid farewell to Kenneth Allen, the well-loved friend of his associates, not only in New York, but throughout this country and abroad. We shall miss the quarterly review of happenings in the sewage treatment field, as so ably selected and edited by Mr. Allen for the New York City Board of Estimate and Apportionment. It was a unique service made valuable by the level head and sane judgment of the editor and abstractor.

It is an unusual coincidence that Prof. Phelps returns with the publication of a paper on stream pollution at the time Kenneth Allen leaves the field. Prof. Phelps years ago contributed so much to the science of sewage treatment and stream pollution that he can never be alienated from our work, even though his own path has diverged in late years to more academic fields. During his early work at the Technology Experiment Station and throughout his service with the U. S. Public Health Service, Prof. Phelps conceived and developed a new, rational and convincing theory in the study of sewage treatment and stream pollution. His recognition

of the importance of the oxygen balance in the problem of sewage disposal led to the derivation of mathematical formulae of fundamental significance, which have been developed and amplified in the stream-pollution laboratory at Cincinnati to such an extent that the work of Phelps, Streeter, Theriault, Hoskins, *et al.*, has established a world-famous technique in the study of stream pollution and self-purification. The simpler concepts of this technique are explained by Prof. Phelps in his short article in this issue. May the New York Sewage Works Association continue to revive his interest in our problems!

Kenneth Allen always wrote clearly and accurately. His translation of the Elsner-Spillner work on sewage sludge some 18 years ago was the first of his many services in clarifying and advancing the science of sewage treatment. He was always sought after for committee work because of his reliability, thoroughness and accuracy. Above all, some of the younger men will remember his kindly, courteous consideration and his willingness to add to their knowledge of sewage treatment.

The New York Association and the Sewage Works Federation will miss Kenneth Allen.

Proceedings of Local Associations

New York State Sewage Works Association
Second Fall Meeting

Syracuse, New York

September 13, 1930

The fall meeting of the New York State Sewage Works Association was held at the Onondaga Hotel, Syracuse, N. Y., September 13, 1930.

Eighty members and guests were registered. Mr. C. A. Holmquist, President, presided and paid tribute to the memory of Kenneth Allen, founder and first president of the Association. The announcement of the passing of Mr. Allen was a distinct shock to all present. The following resolution was adopted:

"The members of the New York State Sewage Works Association, assembled in meeting at Syracuse today, have been shocked and saddened by the announcement of the removal from our fellowship of our friend and first President, Mr. Kenneth Allen.

"Many of us have had the advantage of personal contact and long friendship with Mr. Allen and recognize his sterling character, his helpful criticism, his habit of thorough research and his sane and sound conclusions.

"At all times he has preserved his kindly and helpful attitude and his sense of humor which endeared him to all his associates.

"Therefore be it

"*Resolved:* That we, his fellow members, in recognition of his life and work and his services to this Association, transmit this memorial to his family and spread the same upon our Minutes."

Following a brief business meeting, two papers were presented, one on "Chlorine Uses at Sewage Plants" by L. H. Enslow of the Chlorine Institute, and the other on "Stream Pollution from the Operator's Standpoint" by Professor E. B. Phelps of Columbia University. (The latter paper is published in this issue.) The discussion of the papers was respectively opened by Mr. C. R. Cox and Mr. A. F. Dappert, both of the State Department of Health.

At the luncheon, Dr. George Ruhland, Health Commissioner of Syracuse, welcomed the members and gave a most interesting address on "The Relation of the Sanitary Engineer and the Health Officer in Community Health Protection."

In the afternoon an instructive inspection trip was made to the main sewage treatment works of the city of Syracuse, the Solvay lime wastes beds where the sludge is disposed of and to a small plant at Eastwood where separate sludge digestion and control were demonstrated.

After a dinner in the evening, a lively round table discussion was held, Vice President Morris Cohn presiding. R. S. Rankin, John F. Skinner and Harry W. Eustance led the discussion on the following topics, "Metal Preservation Above and Below Sewage Surface," "Garage Wastes" and "Experience with Small Pumping Stations." A paper prepared by Dr. J. F. T. Berliner on "The Ammonia-Chlorine Treatment of Sewage" was read by Mr. West.

The next meeting of the Association will be the Third Annual Meeting and will be held in Albany at the time of the winter meeting of the New York State Conference of Mayors.

California Sewage Works Association Minutes Third Annual Convention

October 8 and 9, 1930

Morning Session, October 8

Meeting called to order by President Batty. Reports of Committees.

Membership Committee. Philip Schuyler reported that members of his committee had worked individually; he had used the Western Construction News for publicity, and in particular R. F. Goudey had influenced many members to join. Present membership is 224.

Industrial Wastes Committee. No report.

Publicity Committee. Alexander Bell reported that before the spring meeting he sent out copy to northern California newspapers from San Francisco and A. K. Warren sent it out from Los Angeles to southern California papers, but only about five per cent of the editors availed themselves of this copy. From experience at the spring meeting he felt personal contact would produce better results than newspaper publicity and suggested that commercial men in their travels could easily mention the Association and stress the necessity of city officials having representatives at the meetings. Mr. Warren agreed with Mr. Bell on personal contact but suggested that individual members on their return home give the local newspapers an account of what took place at the Long Beach meeting. He also suggested that all members do what they can to contact city officials and not leave it up to commercial men alone. Mr. Schuyler stated that in attempting to get publicity

for a state-aid laboratory he had run against a stone wall, but noted recently that a new mosquito abatement district in Alameda County got "lovely" publicity over the killing of some thirty billion mosquitoes. He thought items of local interest could be given by the local man to his home town paper.

Editorial Committee. E. A. Reinke reported that work done was the same as previously. The 1929 Journal was published and the 1930 Journal under way. He asked for suggestions for additional material.

Legislative Committee. B. J. Pardee stated that no report had been prepared.

Auditing Committee. F. D. Bowlus reported books in satisfactory condition and balance on hand of $85.05.

Award Committee. A. M. Kivari read the report in the absence of Chairman Reynolds, asking that the award be delayed until the spring meeting to allow better opportunity for systematic method of granting the award. President Batty approved the extension of time.

Standard Report Forms Committee. A. M. Rawn presented two summary cost forms which will be printed in the 1930 Journal. The committee felt it undesirable to present detailed cost sheets at this meeting. He suggested that a committee be continued until spring to try out the forms with various plants and operators and see what results may be obtained. He also suggested for the committee that the Professor of Sanitary Engineering of Stanford, the Professor of Sanitary Engineering at California and the Chief Engineer of the State Department of Public Health be appointed as a committee to select not less than three nor more than five plants each year to be submitted to the Board of Direction of the Association and they to canvass the plants with standard forms before making the final award.

Moved by A. J. Smith, seconded by W. A. Allen and unanimously carried that the forms committee as constituted be continued to the spring meeting.

Nominations Committee. A. M. Rawn reported the following nominations:

For *Director*—F. A. Batty, Los Angeles.
President—B. J. Pardee, Visalia.
First Vice President—W. A. Allen, Pasadena.
Second Vice President—John Jacobson, Davis Farm.
Secretary Treasurer—E. A. Reinke, Berkeley.

Moved, seconded and carried that nominations be closed.

Moved, seconded and unanimously carried that the Secretary be instructed to cast unanimous ballot for those named by the nominating committee.

Treasurer's Report. E. A. Reinke presented a written report showing

cash on hand of $85.05. This amount is less than a year ago but we have no hold-over bills this year.

Secretary's Report. E. A. Reinke presented a written report showing 224 members, an increase of 17 over last year.

No further business appearing, a five-minute recess was declared.

A paper on "Odor Control by Design and Operation," written by John Jacobson of U. C. Farm, Davis, was read by C. G. Gillespie, and discussed by Messrs. Hilton and A. J. Smith.

A paper on "Odor Control by Chlorination" was read by L. L. Rose of Los Angeles and discussed by F. S. Currie, R. L. Patterson, R. F. Goudey, H. H. Hall, A. M. Kivari, W. T. Knowlton, C. A. Smith, and Philip Schuyler.

Dr. Carl Wilson, of the Los Angeles City Water Department, in discussing cost of sewage treatment, stated that he believed in arid country at least reclamation of water could be made to pay all or a large part of the cost of sewage treatment. In reply to a question by Philip Schuyler he stated that sewage could be considered as the waste or byproduct of the water works industry, and the property of the water works man.

In reply to a question by E. A. Reinke as to suitable paints on wood and metal Carl Tennant and J. H. Van Norman reported that aluminum paint was better than asphaltic base paint. W. A. Allen reported that non-metallic base paints give good results at Pasadena.

The meeting was adjourned at 11:30 a.m.

Luncheon and Afternoon Session, October 8

A caravan of 46 cars was formed and members visited the Pacific Clay Products Company plant at Los Nietos, where manufacture and testing of pipe was demonstrated. A delightful luncheon was served by the company with music furnished by an employees' band.

The caravan proceeded to the Pasadena Activated Sludge Plant, which was explained by Superintendent Wyman and Assistant Superintendent Allen; then to the experimental plant of the Los Angeles City Water Department, which was explained by R. F. Goudey, Sanitary Engineer.

Morning Session, October 9

A caravan of 28 cars was formed at Hyperion Screening Plant of the City of Los Angeles, which was explained by J. H. Van Norman and his staff.

The caravan proceeded to the Los Angeles County Sanitation District Plant at Poggi Ranch, which was explained by Assistant Chief Engineer, A. M. Rawn.

The trip was continued to Wilmington, where a maintenance crew from the City of Los Angeles, under F. A. Batty, demonstrated various methods of sewer cleaning.

Luncheon and Afternoon Session, October 9

A group of 105 assembled at the Hotel Breakers, Long Beach, for lunch. Mayor A. E. Fickling was guest of honor and officially welcomed the Association to Long Beach. Following the meeting a group photograph was taken.

The afternoon session was called to order by President Batty.

Papers on "Handling Sludge and Screenings" were read by T. R. Haseltine of Salinas, A. P. Banta of the Los Angeles County Sanitation Districts and Herbert Paterson, City Engineer of Long Beach. Discussions were given by R. F. Goudey, M. C. Polk and D. C. McMillan.

A paper on "Handling Sludge and Screenings" was read by A. W. Wyman, of Pasadena, stressing fertilizers. The paper was discussed by A. S. Thornton, who sells "Nitroganic," from Pasadena, and H. Clay Kellogg, who handles "Sludgen," from Los Angeles County Sanitation Districts, Pomona, Whittier, San Bernardino and Orange County.

Papers on grease removal were read by W. A. Allen, on "Imhoff Method" and by G. A. Parkes, on "Los Angeles Method." A written discussion by G. C. Zuckweiler was not read because of lack of time, but will be published in THE JOURNAL.

Mr. W. T. Knowlton presented a resolution extending thanks to the Mayor, City Council and Chamber of Commerce of the City of Long Beach; the Pacific Clay Products Company; the Vitrified Clay Pipe Manufacturers; and the retiring officers of the Association for their work in bringing about a successful meeting. The resolution was amended by Chester Smith to include the City Engineer of Long Beach. Another resolution concerning legislation for sewage maintenance was also presented.

Moved by Mrs. Christensen, seconded by Mr. Perry, and unanimously carried that both resolutions be adopted.

Philip Schuyler thanked the Association for the gift of golf clubs and bag presented to him following the spring meeting, and pledged the continued support of the *Western Construction News*.

President Batty turned the meeting over to President-elect B. J. Pardee, who expressed thanks for the honor and asked assistance of the members to make the Association the greatest of its kind.

Meeting adjourned. Following the meeting a group of members visited the Long Beach Screening Plant and one of the sewage pumping stations, under the guidance of City Engineer Paterson.

Respectfully submitted,

E. A. REINKE, *Secretary*.

Reviews and Abstracts

H. W. STREETER

Proceedings of the Association of Managers of Sewage Disposal Works

London, England (1929), 225 pp.

ABSTRACTED BY H. GLADYS SWOPE

These *Proceedings* publish the papers presented during 1929 at the various meetings of the Association held throughout Great Britain.

At the Leeds meeting of the Yorkshire District, held January 19, 1929, two papers were presented, one on "Suction Gas as a Motive Power" by Mr. F. Hall and the other by John H. Spencer entitled "Some General Thoughts on Sewage." Mr. Hall reported that he had found an oil engine more efficient than a gas engine. Mr. Spencer stated that with a given type of plant the per cent purification of strong sewage is greater than of weak sewage. This follows from the chemical law of mass action. The more dilute sewage, however, contains more dissolved oxygen, which aids during biological purification. Colloids are of primary importance in sewage treatment. They may be removed by coagulation or by oxidation or reduction of the protective colloids.

"An Introduction to Bacteriology" was presented by Dr. Sciver, of the Battersea Polytechnic Institute, at the Battersea meeting, January 31, 1929. Sewage purification is essentially a bacteriological process. Treatment usually takes place in two stages, which are (1) liquefaction and solution of solids in suspension (anaerobic) and (2) oxidation of substances in solution (aerobic).

The extension to the Epsom surface aeration plant was discussed by Edward R. Capon at the Epsom meeting February 16, 1929. The paper was abstracted in THIS JOURNAL, **I,** 508 (July, 1929).

Mr. W. S. Jackson of the West Riding Rivers Board presented a paper on "Stream Flows, Storm Water Overflows and Separation Weirs" at the Wakefield meeting February 23, 1929. Six methods for stream-flow measurements are (1) cross sections and floats, (2) cross sections and current meters or pitot tubes, (3) cross sections and surface slope, (4) measurement over existing weirs, (5) temporary dams and rectangular weirs or v-notches, (6) gauging the flow by chemical means. A properly designed storm-water overflow should separate the excess storm water not required to be treated at the outfall works, and prevent fouling of the streams with floating sludge.

The Huddersfield bio-aeration plant was described by W. D. Scouller at the meeting in Leeds, March 16, 1929. The sewage consists of domestic, textile, and chemical wastes. All of the trade wastes are discharged directly into the sewer, this being allowed through the Huddersfield Corporation Act of 1906. The first plant was constructed in 1893 and consisted of tanks and sand and polarite filters. Later the filter material was replaced by clinker. In 1909 a new project consisting of tanks, percolating filters and humus tanks was put into operation. This was satisfactory until 1915 when chemical wastes began to be discharged. The textile mill wastes contained a large amount of grease and fatty matter. A grease recovery plant was installed by the corporation and fertilizer was made from the residue which had previously been lagooned. As the chemical plants were adjacent to the sewage works, separate sewers were installed for these wastes, which were given preliminary treatment in settling tanks, built in 1924. The chemical wastes are settled, treated with a precipitant, further settled and this effluent then mixes with the sewage and is treated on filters and in the bio-aeration plant. The substances which inhibit purification are iron salts (above 100 p. p. m. Fe), acids and dyes. The chemical wastes have a 4-hour oxygen absorbed value of 500 p. p. m., as compared with 200 p. p. m. for the domestic sewage containing the textile wastes. The new bio-aeration tank (built in 1928) is of the Haworth type. The tank is 280 ft. long and 4 ft. deep with 24 channels each 6 ft. wide. The total capacity is one million gallons, which is the average daily flow. There are 8 sludge separating tanks of the Dortmund type, each having a capacity of 39,100 gallons. The volume of sludge in the aeration tank has been kept at 13 per cent. The bio-aeration effluent has contained from 26 to 37 p. p. m. suspended solids.

On March 23, 1929, at the Manchester meeting, J. P. Todd presented a paper on "The Principles of Electrical Measurement." He discussed the elementary principles of electricity and described the kinds of instruments used and their mathematical interpretation, for indicating voltage and current. Diagrams were used to illustrate his descriptions.

"Chingford Sewerage and Sewage Disposal" was discussed by Mr. Martin at the Chingford meeting May 4, 1929. The original disposal works consisted of tanks only, but five trickling filters (three high-level and two low-level), with rotary distributors, and a humus tank were added in 1906. Due to the great increase in population, both the sewers and treatment plant were overtaxed and in 1924 a new scheme was prepared. In 1926 work was started on a larger plant consisting of two detritus and screening chambers, four primary settling tanks, one secondary settling tank, four sludge digestion tanks, eight trickling filters, two humus tanks and a humus pond. The sedimentation and sludge digestion tanks are

octagonal in plan. Four of the new filters were inoculated with *Achorutes Viaticus* when put into operation. The filter stone has remained quite clean, probably due to their action. The filtered effluent uniformly contains 40 p. p. m. nitrate nitrogen. The sludge from the sedimentation tanks is digested in separate tanks. The digested sludge is run onto land to dry. Arrangement is provided to collect the gas from the digestion tanks if it is wanted. The filters operate with Ames Crosta distributors, which work with a head of only 9 inches between the invert of the sewer and the surface of the filters.

Mr. Walter F. Freeborn of Manchester presented before the Annual Summer Conference at York, July 5 and 6, 1929, a detailed paper on "The Costing of Sewage Disposal Works." This paper was abstracted in THIS JOURNAL, **II,** 58 (January, 1930).

"The Treatment of Spent Gas Liquors" was discussed by Dr. Allan C. Monkhouse of Leeds, at this Summer Conference. The admission of spent gas liquors to sewers has been detrimental to bacterial purification at various sewage treatment plants. Accordingly, in June, 1926, the gas industry appointed a committee to investigate methods for minimizing these wastes and rendering them innocuous. The spent gas liquor is the effluent derived from the conversion of ammonia liquor into ammonium sulphate or liquid ammonia. The product most commonly prepared is ammonium sulphate. Two effluents are produced in this manufacture, the "devil" liquor, which is condensed in the coolers, and the spent liquor from the still. The noxious constituents are the phenols, higher tar acids, thiocyanate and thiosulphate. With vertical retorts there is less "cracking" of the tar and the proportion of higher tar acids is greater than with horizontal retorts. It has been shown by earlier investigations that proportions of spent liquor up to 9 per cent of the sewage flow can be treated on suitably matured bacterial filter beds. At the Hinckley Gasworks experiments were made to determine (*a*) the conditions of maturing or "seeding" of a filter bed by means of town sewage; (*b*) the degree of purification obtained with mixtures of town sewage and vertical-retort spent liquor in different proportions by single and double filtration; and (*c*) the degree of purification of effluent spent liquor, suitably diluted, on a filter bed previously matured by town sewage and spent gas liquor.

The results showed that if the beds are matured with domestic sewage alone and then the spent liquor added in gradually increasing proportions to 8 per cent of the domestic sewage that it may be applied at a rate of 60 gallons per cu. yd. per day. When two beds were operated in series, 65 per cent purification was obtained in the first bed and 85 per cent for the two beds. At the Foleshill Works of the Coventry Corporation, large-scale percolating filters (about one acre) were installed to treat only the spent gas liquor. The beds were matured with crude domestic sewage,

diluted with brook water and purified effluent, and humus. Only a small amount of the spent liquor was added at first but this was gradually increased until 40,000 gallons per day was treated, the dosing rate being 122 gallons per cu. yd. per day. The addition of sewage was discontinued when the beds were matured. A purification of 93 per cent was obtained based on the oxygen absorption figures. The disadvantages of the method are the large area required, and the high initial and running costs. Attempts are therefore being made to reduce the amount and concentration of spent liquor effluent. The spent gas liquor can be evaporated, thus reducing the work of purification about 20 per cent. Experiments have been tried for removing the phenols by volatilization, by washing with solvents, or by means of active carbon. Oxidation with ozone and bleaching powder have been suggested but the methods are too expensive for industrial purposes. Experiments are under way to modify the processes of gas works manufacture in order to reduce the amount of higher tar acids. These can be reduced by removal of the heavier tar at a temperature above the dew-point of the gas before condensation of the liquor. For these experiments a tar extractor was used, consisting of a restricted gas main in which a finely divided spray of liquor at 50 lb. per sq. in. impinged on the gas stream. The volume of tar increased from 4.7 to 12.6 gallons per ton of coal carbonized and the higher tar acids were reduced. An experimental Cottrell precipitator increased the recovery of tar from 6.7 to 16.1 gallons per ton. This method is to be further investigated. An interesting and lengthy discussion followed the paper.

At the Chesterfield meeting, held July 20, 1929, the sewage treatment works were described by Mr. Thornhill, Chemist and Manager. The sewage from the population of 66,450 contains both domestic sewage and trade wastes. The trade wastes comprise spent gas liquors, keir liquor, bleach wastes, spent pickling acids, tempering and hardening oils, tannery wastes, brewery wastes, and various dyes. The dry-weather flow is 1,750,000 gallons per day. The treatment works include detritus tanks, preliminary settling tanks, bio-aeration units with mechanical agitation, and final settling tanks.

The Haworth bio-aeration units are in three batteries of tanks, each of which is 242 ft. long by 87 ft. wide by 4 ft. deep. Longitudinal walls $3\frac{1}{2}$ in. thick divide each battery into 14 channels 5 ft. 6 in. wide. The total capacity is 1,750,000 gallons, equal to the daily flow. The paddles are 10 ft. in diameter 2 ft. wide with 8 arms. The wheels revolve at 15 r. p. m. and produce a velocity of 1.6 ft. per second.

There are 15 final settling tanks, each 24 ft. square and 22 ft. deep, with a total capacity of 562,000 gallons.

The effluent is discharged directly into the river. Under-drained sludge lagoons have an area of 15,000 square yards. The surface water is drained

off after one hour's settlement. The air-dried sludge is taken off the beds and removed by farmers and others.

"Some Points Regarding Activated Sludge Process" was the title of a paper presented by J. E. Farmer, Manager of the Croydon Sewage Works, at the annual meeting of the Metropolitan District November 16, 1929. The Croydon "Simplex" plant comprises 3 units, each containing an aerating chamber with two aerators, a four-stilling-box settling chamber unit, sludge well and pump. The plant is so laid out that it can be operated in parallel or in series. The raw sewage has an oxygen absorption in 4 hours of 102 p. p. m. and 362 p. p. m. suspended solids. The Simplex aerators revolve at 32 r. p. m. and 5 per cent sludge has been carried in circulation. The power used by the Simplex aerators has been 7.5 H. P. per million gallons, but only partial purification has been obtained.

The various factors affecting the efficiency of the activated sludge process were discussed. Further experiments are planned at Croydon.

At the Public Works, Roads and Transport Congress and Exhibition, held under the auspices of this Association in London, November 21, 1929, Mr. F. C. Temple, Chief Town Engineer of Jamshedpur, India, spoke on "Successive Separation in Sewage Disposal Systems." He discussed the development of various methods of treating sewage, including the septic tank, the Imhoff tank and bio-aeration. An ideal installation might contain ten separations; screening, grit catching, preliminary settling of sludge, sludge digestion, preliminary bio-aeration, further bio-aeration, final settling and sludge drying. The paper was discussed at length. The other paper presented at this Congress was "The Application of Bleaching Powder as an Auxiliary Treatment of Sewage" by Herbert D. Bell of Barnsley. An abstract of this paper appeared in THIS JOURNAL, **II,** 183 (January, 1930).

This review cannot include the very interesting and valuable discussions which follow the papers presented before the British Association. The *Annual Proceedings* may be obtained from the Secretary Mr. J. B. Croll, at 1, Main Drainage Works, West Hall Road, Kew Gardens, Surrey. Dr. Edward Ardern of Manchester is President for 1929–30.

Regional Control of Sewage Purification Works

BY H. C. WHITEHEAD, M. INST. C. E.

Journal of the Royal Sanitary Institute, **51,** No. 3, pp. 140–143 (Sept., 1930)

ABSTRACTED BY KATHLEEN MEAGHER

An extension of regional organization and regional scientific control of sewage and trade wastes purification is offered as a more economic solution to the river pollution problem in England than an increase in the

number of river pollution boards. The advantages of such a system would be:

1. A higher standard of scientific control and better value in purification without increased cost to the public.

2. A reduction in the number of sewage purification works with retention and expansion of the most efficient plants.

3. Elimination of nuisance from odor and appearance of purification works by pumping sludge five or ten miles from the plant to a rural area for subsequent digestion in joint sludge treatment works. Thus valuable urban sites would be made available for purposes other than the drying and lagooning of sludge. The comparative economy of this method is demonstrated by the fact that two sewers each 8 ft. in diameter are required to convey six times the dry-weather flow of sewage from a population of 1,000,000 people to a new site for purification, whereas only one pumping main 12 in. in diameter is needed to convey all the sludge from a group of purification plants, treating sewage from the same population, to a separate sludge treatment works. Such practice would result in marked economies in future sewerage and pumping costs.

4. Experimental investigation carried on under central authority would result in savings in construction and working costs and would not be confined to local treatment plants.

The author and those who discussed the paper also emphasize the need of cultivating a public opinion which will not tolerate river pollution and the overcoming of local jealousies in the event of the establishment of central authority.

Annual Report of the Department of Sewage Disposal New Jersey Agricultural Experiment Station July 1, 1928–June 30, 1929

BY WILLEM RUDOLFS

ABSTRACTED BY E. HURWITZ

Rudolfs, Downes and Henderson report on the "Operation of Two Separate Sludge Digestion Tanks" at Plainfield. The tanks were designed for a total capacity of 20,000 cu. ft. and are equipped with floating covers. During the year the two tanks handled 214,250 cu. ft. of fresh solids and partly decomposed material and 212,175 cu. ft. of sludge and liquid were withdrawn. The amount of lime used for reaction control averaged 7.5 pounds per 100 cu. ft. The average pH of the sludge was 7.4. More fresh solids were handled during the summer months than during the winter. The average solids concentration of the fresh solids was about 5 per cent and of the sludge withdrawn 7.25 per cent. The ash content of the

fresh solids ranged between 20 and 25 per cent. The sludge withdrawn contained 47.5 per cent ash.

Rudolfs and Lacey report on "Some Operating Results of the Plainfield Sewage Disposal Plant." Sewage reaching this plant is fairly old, an average of 6 hours, and is stale and well comminuted. In spite of this fact and of the fairly short detention period, 40 minutes, the settling tanks removed 53 per cent of the total suspended solids in addition to the 9 to 12 per cent removed by the Reinsch Wurl screen. Total reduction in B.O.D for the settling tanks and sprinkling filters was 56.2 per cent, three-fourths of which was removed by the filters.

"Performance of the Tenafly Activated Sludge Plant" is reported by Rudolfs, Heukelekian, Lacey and Henderson. The plant is designed for 750,000 g. p. d. and is equipped with a 2-inch bar screen, a Link Belt fine screen, Dorr clarifiers, sand beds, chlorination unit, and two glass-covered sludge beds. The borough is provided with a separate sewer system and the sewage reaching the plant is strictly domestic. Operation was started in February, 1928. In July, 1928, the efficiency of the plant was determined by tests over a thirty-six hour period, during which samples were collected at $1^1/_2$-hour intervals for chemical and bacteriological analyses. The average B. O. D. and *B. coli* count, together with their percentage reduction are given in the table:

	B. O. D.		*B. coli*	
	P. p. m.	Per ct. Reduction	*B. coli* per cc.	Per ct. Reduction
Influent	95	..	22,970	..
Clarifier effluent (activated sludge effluent)	14	85.3	3,090	86.5
Sand bed effluent	9.6	89.9	134	99.5
Final effluent (chlorinated)	6.2	93.5	0.74	99.99

"The Effect of Certain Chemicals on the Vacuum Filtration and Gravity Drying of Ripe Sludge" was studied by W. H. Baumgartner. Ferric chloride, ferric aluminum sulphate, sodium aluminate, and sodium aluminate in a solution containing caustic soda were used as conditioning agents. Preliminary laboratory experiments were made to determine the most effective agent. These tests showed an increase of more than 100 per cent in the amount of filtrate from the sludge treated with $FeCl_3$ as compared with the untreated, for any given period of filtration. The other three conditioning agents used did not even approach the effectiveness of $FeCl_3$, although they showed an improvement over the untreated. Other laboratory experiments tended to show that from 2 to 4 pounds per cubic yard was the most economical amount of $FeCl_3$ for practical use; that the moisture in the filter cake was inversely proportional to the amount of $FeCl_3$ used; and that there seems to be a definite relation between the pH value of the

$FeCl_3$ treated sludge and the amount of filtrate produced in a given time interval.

For the field experiments the bed was divided down the middle so that a blank test could be made using the same sludge as that used with the $FeCl_3$ and under identical climatic and other conditions. The sludge was drawn on the bed to a depth of 9 inches. The first bed was drawn in mid-winter. To the treated portion 2.4 pounds of $FeCl_3$ per cubic yard was added. Inclement weather interfered somewhat with these tests but the moisture content, which was determined at irregular intervals, was slightly lower for the treated than the untreated sludge. The moisture of the untreated sludge reached its lowest value, 84.3 per cent in six days and then it increased slightly until on the tenth day it was 85.6 per cent. This condition was probably due to the melting of snow which occurred during this period. The sludge treated with $FeCl_3$ apparently was not affected in this way. On the sixth day the moisture content was 83.6 per cent, which decreased to 82 per cent in ten days. The test was not carried further than ten days. It is uncertain whether the same trend would obtain over a longer period.

In July another bed of sludge was drawn. This time 4 pounds of $FeCl_3$ per cubic yard was added. There were no adverse weather conditions and very little rainfall during the test period. The treated sludge in this case also showed small but consistent reductions in moisture content over the untreated. From an original moisture content of 94 per cent, the conditioned material decreased to a moisture content of 76 per cent in 6.8 days as compared with 8.6 days for the unconditioned material, a difference of 1.8 days. Here again the test period of only nine days may have been too short to obtain conclusive evidence as to the value of $FeCl_3$ in drying ripe sludge on sand beds.

For the ten-day period covered in these tests the sludge conditioned with $FeCl_3$ had a tendency to dry faster and better than the unconditioned material. This influence of $FeCl_3$ on drying and its influence on filtration of sludge is explained by its ability to bring about the coagulation of dispersed material; to change the pH so that it approaches the iso-electric point, where maximum precipitation of colloidal material takes place; and to liberate CO_2, which tends to make the material more porous and to help in its flotation.

Studies on "Sludge Drying: Relation Between Drainage and Evaporation" were reported by Rudolfs and Lacey. Portions of ripe sludge, 100 cc. each, were poured onto a wet filter paper in a Büchner funnel and the filtrate (drainage) measured in a graduated cylinder. The difference between this drainage and the total loss in weight was called loss due to evaporation. The experiments were conducted at 43°, 74°, 100°, 113° and 131° F.

Average results of four experiments show that during the first 8 to 10 hours drainage is rapid in all cases and temperature has negligible influence. After this period the material subjected to the highest temperature drains somewhat more slowly than that kept at the lowest temperature. Evaporation on the other hand is not an important factor at temperatures below 100° F. and it is not until a temperature of 130° F. is maintained that the rate of evaporation exceeds the rate of drainage in a 24-hour period. The authors use these facts to point out that glass covers for drying beds are not essential from the standpoint of evaporation inasmuch as rapid greenhouse drying would require the maintenance of a temperature of 130° F. and the removal of the evaporating moisture.

Under the title "Notes on Drying Fresh Sewage Solids," Fischer reports the results of some laboratory and field tests made on the drying of fresh sewage solids using heat and chemicals as conditioning agents. Laboratory experiments were made first and the most effective chemicals were tried in the field. Alum, lime and mixtures of these were chosen for the field work and were tested by air drying both on soil beds without underdrains and on underdrained sand beds. These experiments resulted in the conclusion that the drying of fresh solids in the open was not feasible when treated with lime, alum or a mixture of lime and alum, on account of poor drainage, objectionable odors or both.

"Certain Organic Constituents of Fresh and Ripe Sewage Sludge," reported by Heukelekian, gives the analysis of the organic matter content of fresh solids and ripe sludge in greater detail than has heretofore been reported in the literature. The method used was similar to that used by Waksman and Stevens in their study of the composition of peat. The results show that in fresh solids the ether soluble portion (fats) comprises about 35% of the total solids, crude protein is next with 27 per cent; about 8.5% is soluble in water; 2.5% in alcohol. Hemicellulose comprises 3%; cellulose about 4%; lignin 6% and ash, 24 per cent.

In the ripe sludge the fats comprise only 8% of the total solids; crude proteins 20%; water soluble 6%; alcohol soluble 2%; hemicellulose 2%; cellulose $^1/_2$%; lignin 8%; and ash 56 per cent.

The table below shows these results calculated on per cent volatile matter basis and gives the reduction of each constituent after digestion.

	Fresh Solids	Ripe Solids	Reduction
Ether soluble	44.0	19.0	−57.0
Water soluble	11.0	12.9	+17.0
Alcohol soluble	2.6	3.9	+50.0
Hemicellulose	5.8	4.0	−31.0
Cellulose	4.7	0.0	−100.0
Lignin	5.5	20.0	+260.0
Crude protein	35.8	44.7	+25.0
	109.4	104.5	

The table shows a marked decrease in the fat and cellulose content of the volatile matter; no appreciable change in the water-soluble and hemicellulose, indicating that this material decomposes at about the same rate as the whole group designated as volatile matter; the lignin, crude protein and alcohol-soluble fractions increased considerably, indicating that these substances decompose very slowly, so that the volatile matter of the decomposed sludge had actually higher percentages of these substances than the original sludge.

The annual report includes also a report of the coöperation of the Department of Sewage Disposal with the Department of Institutions and Agencies; a brief report by Rudolfs of some experiments conducted on the action of the sprinkling filters at Plainfield; and abstracts of various papers published by the department during the year.

The Iserlohn Treatment Plant
The First Activated-Sludge Plant Operated by Power from Sludge Gas

BY WALTER SCHMIDT, RUHRVERBAND

Technisches Gemeindeblatt, **33**, 133 (June 5, 1930)

ABSTRACTED BY G. P. EDWARDS

The Iserlohn treatment plant of the Ruhrverband was built in 1913 and was placed in operation during the spring of 1914. The sewage treated is domestic in nature and amounts to about 40 gallons per capita from the 19,000 inhabitants of Iserlohn. The sewage is very strong and although it usually arrives at the plant in a fresh condition, occasionally it is very septic because of the discharge of privies collected from the unsewered section of the town. Since the effluent from the plant discharges in the Baarbach, a small stream often dry during the summer, purification must be as complete as possible.

The original plans called for a 1.5 in. coarse screen, two storm-water clarification tanks, three grit chambers and six Imhoff tanks. The detention period in the Imhoff tanks was six hours, which would be cut down to two hours during storms. The remainder was settled in the storm-water tanks, where, with a capacity load, the settling period was three-quarters of an hour. The effluent from the storm-water tanks and the Imhoff tanks discharges into the Baarbach. After a storm the liquid and sludge from the storm-water tanks are gradually discharged into the influent channel of the treatment plant above the grit chambers. These storm-water tanks

will be useful after the construction of the secondary purification plant, since they equalize the flow during storms.

In 1927, because of complaints from property owners along the Baarbach, secondary purification was necessary and an experimental submerged contact aerator was built in the settling chamber of an Imhoff tank. The power needed for compressing the air and for the swinging pipe was obtained from the Imhoff tank gas. The motor using the gas was obtained from the Deutz Motor Works and furnishes 10 h. p. This motor, although built for use with coal gas, operates successfully if a larger air supply is used with the digestion gas, which has a high heat value.

Since enough contact aerators could not be built in the Imhoff tanks, it was clear that the purification would not be sufficient and activated sludge was planned to supplement the treatment. In 1928, grease traps, new submerged contact aerators, which were placed in special tanks, and activated-sludge tanks were built. Digestion gas is used to operate the Deutz motors, which furnish the power for the entire plant. The purified sewage is used for cooling water in the motor and the warm water from the cooling coils serves to heat the sludge in the Imhoff tanks. The excess activated sludge and the sludge from the contact aerators are digested in the Imhoff tanks, increasing the gas yield. This is the first plant in which all the power required for the activated sludge process is obtained from its own digestion gas.

The detention periods are as follows:

Imhoff tanks	3 hours
Submerged contact aerators	1 hour
Contact aerator settling tank	1/2 hour
Activated sludge aeration tank	5 hours
Activated sludge settling tank	1 1/2 hours
Total	11 hours

In the grease traps the sewage is aerated 2–3 minutes and the grease which collects on the surface is removed from time to time and burned. Baffles in the grit chambers and turbulence in the sewage, caused by a fall of about a meter, aid in separating the grease.

The submerged contact aerators were built to act as a sort of buffer to protect the activated sludge tanks when the sewage is septic. Eight contact aerators were built in a tank 42 ft. long and 13 ft. wide and 10 ft. effective depth. A hopper-shaped settling tank, 26 ft. effective depth, is used for settling. Laths supported by iron frames were placed at an angle so as to offer resistance to the air. This arrangement has the advantage of being easily cleaned and repaired.

The activated-sludge system consists of two aeration tanks each 82 ft. long, 20 ft. wide, with 10 ft. effective depth, and two funnel-shaped settling

tanks with 26 ft. effective depth. Porous plates and paddle wheels similar to those at Essen-Rellinghausen are used in the aeration tank. The sludge enters the settling tank below the surface of the liquid through a down well. The sludge sinking through the rising liquid exerts a filtering effect. The settled sludge is removed continuously and part is returned to the aeration tanks. The excess is pumped to the Imhoff tanks.

The gas collected in 12 gas domes is measured and pumped to the motor and to a gas tank 880 cu. ft. in capacity. In 1928 the amount of gas produced per day varied from a maximum of about 10,000 cu. ft. in July to a minimum of about 5000 cu. ft. in January, with an average of 6600 cu. ft. per day. This is a yearly average of about 0.33 cu. ft. per capita per day. The motors which generate the 20 h. p. required about the plant consume about 6000 cu. ft. of gas per day. When the gas from the digestion of the excess activated sludge is included, there will probably be enough gas produced each day throughout the year to operate the motors. When the gas produced is not sufficient, the motors can be operated with benzine by making a slight change in the carburetor. No electrical connections are available.

The power requirements are distributed as follows:

Swinging pipe—submerged contact aerator	1 h. p.
Paddle wheels, activated sludge	8 h. p.
Aeration (8700 cu. ft. per hour) contact aerator, grease traps—pump in activated sludge settling tank	5 h. p.
Aeration (8700 cu. ft. per hour) activated sludge tank	5 h. p.
Blower for reserve purposes	5 h. p.
Pumping drinking water supply	0.25 h. p.
Cooling water supply for gas motors	0.25 h. p.
TOTAL	24.50 h. p.

The cost of construction of the new plant, including the attendants' house and enlargement of the sludge-drying bed, was about $45,000 or about $2.38 per capita. The cost of the gas-collection apparatus and the gas tank was about $3750 and the extra cost of the motor was $1000, making a total of about $4750. The annual cost of operation using the gas for power is about $1300. The saving due to the use of digestion gas is about $1250 per year.

The new plant was put into operation August 10, 1929. The plant has been operated very well except for temporary disturbances in the activated sludge tanks due to the septic discharge from privies.

A New Activated-Sludge Process without the Use of Compressed Air

BY DR. ING. LEINER, STOLP-RITZOW

Formerly lecturer at the Munich Technical High School

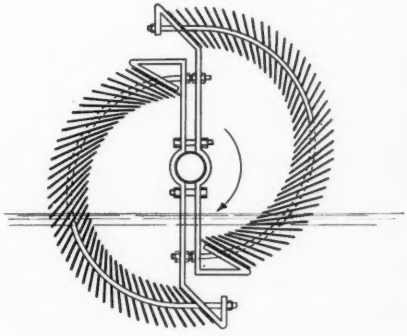
Gesundheits Ingenieur, **53**, 500 (Aug. 9, 1930)

ABSTRACTED BY G. P. EDWARDS

Since the development of the activated-sludge process a great deal of experimental work has been done to obtain aeration by mechanical means. So far, all mechanical systems have required a longer aeration period than is necessary with compressed air. This longer aeration period means a larger aeration tank with increased interest charges and only an apparent saving in the cost of operation.

The diagram shows a new type of mechanical aerator which will yield an effluent containing nitrates with the same detention period as a compressed air system and which requires considerably less power. Boards 5 cm. wide are attached just off center, one slightly lower than the other, on a hollow shaft. Two sets of these activators are required in a tank six meters wide and three meters deep.

When the activator rotates rapidly, air is forced into the liquid and although only a surface layer 10 cm. deep is aerated, the liquid saturated with air sinks to the bottom and there gives off its excess oxygen.



During extreme cold weather, it may be possible to warm the contents of the tanks by circulating warm air through the hollow shafts which carry the activators.

This apparatus is suitable for reaeration of settled sludge or for use where only partial purification is necessary. The activators are cheaper to construct and to operate than submerged contact aerators. All movable parts lie above the liquid and the wooden boards are impregnated with hot paraffin. Constant supervision of operation is not necessary.

Principal and interest and operating costs, including the cost for power and lubrications, are lower than for ordinary activated sludge plants.

In a more recent article,[1] Leiner points out that in a tank 6 meters wide

[1] *Gesundheits Ingenieur*, **53**, 588, Sept. 20, 1930.

and 3 meters deep, the activators should rotate at a speed of 20–25 revolutions per minute. Although the activators are the same size in all tanks the speed of rotation should increase with a larger tank and with a stronger sewage. In small tanks, the speed may be decreased to 14 revolutions per minute.

The location of the boards on the activator also depends on the speed of rotation. The more rapidly it rotates, the more the boards should slope backwards.

Factors in Sludge Digestion

BY M. LUNDIE

Surveyor, **73**, No. 2012, pp. 165–167 (Aug. 15, 1930)

ABSTRACTED BY H. W. STREETER

In the digestion of sludge, the importance of temperature is emphasized by the fact that the biological agencies active therein are sensitive to temperature. For low-temperature digestion, the critical temperature is 18° C. and the optimum, 27° C. Raising it to 37° C. does not accelerate digestion. For heating sludge, hot water pipes are used, and recently Imhoff has introduced hot water at the bottom of the tanks, allowing it to diffuse upward. Studies by Sierp have shown that the specific heat of water and sludge is the same, but that the transfer of heat through sludge by conduction and convection is very slow as compared with the transfer in water, mostly by convection.

The effect of high temperatures on the digestion of sewage solids has not been fully investigated. Thermophilic bacteria, which have an optimum range of 50°–60° C., are spore-bearing and not the same as those active at lower temperatures. The minimum temperature for thermophilic decomposition is 45° C. and the maximum 69° C.

By seeding fresh sludge with ripe sludge obtained under thermophilic conditions, Rudolfs and Heukelekian were able to cut the digestion period to 18–19 days at 45–55° C. At 27° C., 80–85 per cent of the gas is produced in 25–26 days, a longer period being uneconomical. The reduction in time at 45° C. is thus considerable, but whether it is economical depends on conditions. High temperature digestion is accompanied by an intensity of odors. On a laboratory scale, it seems more feasible, but the creation and maintenance of such high temperatures on a large scale is a problem requiring careful investigation.

As regards the influence of solids concentration on the digestion of sludge, experiments on the effect of digesting sludge containing 6, 12 and 18 per cent of solids showed that best results (least tank capacity and

most rapid digestion) were obtained with 18 per cent solids seeded with ripe sludge. Digestion was most rapid when the material was seeded at once, before acidity developed. Concentrated septic sludge, allowed to develop maximum acidity before seeding, required less digestion capacity, but a longer period of time.

The maintenance of high solids content in a digestion tank involves difficulties, notably layer effects, with retarded digestion owing to local concentration of acid products, and excessive scum formation, due to inability of gases to escape. These difficulties can be overcome by effective mixing of raw with ripe sludge and suitable stirring action to allow escape of gases.

It is considered good practice *not* to allow sewage solids to get septic before their introduction into digestion tanks, thereby preventing odors and trouble in subsequent treatment of the tank effluent on filters or by the activated-sludge process. Digestion consists of two phases: (*a*) liquefaction and (*b*) gasification, presumably with different types of flora. There is evidence that liquefaction proceeds under more acid conditions, but no evidence that it must precede, or is dependent on, gasification, though in the acid stage there is an accumulation of liquefied substances which, on neutralization, gasify readily. It thus may be probable that the septicization of solids may be beneficial to subsequent digestion. Experiments on this point at the New Jersey experiment station have indicated, however, that the time required to complete gasification after seeding is the same whether the solids are fresh or septicized and that the total time required is increased by the period of septicity.

The importance of proper seeding cannot be overestimated. In practice, heavy seeding initially is rarely possible; hence in a new tank or where the quantity of ripe sludge is inadequate, optimum conditions of reaction and temperature must be maintained until a sufficient body of well-digested sludge is built up in the tank before daily additions are made of fresh sludge, preadjusted if necessary before introduction to the digestion tank.

The primary objective of sludge digestion being to render unstable matter innocuous and stable, the question arises, "When do we know that digestion is complete?" Usually this is evidenced optically by cessation of gasification and, analytically, by determinations of volatile matter and ash, before and during digestion. Although these figures vary in every sludge, the ash percentage in the dry solids after digestion is often more than twice what it is before digestion. From experiences in partial sludge digestion at Pretoria the author concludes that prolonging digestion to completion is unnecessary, as the primary object of stability may be attained in advance as soon as biological equilibrium has been established.

Small Bio-Aeration Plants

BY H. KESSENER

Surveyor, **78**, No. 2007, p. 59 (July 11, 1930)

ABSTRACTED BY H. R. CROHURST

The recognized hygienic advantages of the activated-sludge process are of importance in treating the sewage from institutions where proximity of plant to buildings is a factor. Such plants will be preferred if they do not require more attention than other types and if the power consumption is in proportion to the size of the plant.

An attempt by the author to develop a unit, automatic in so far as is possible and of efficient equipment to minimize power consumption, has resulted in the use of brushes for suface aeration and a water wheel for the return of sludge. Revolving brushes about two feet in diameter are placed at one side and lengthwise of the tank to produce a vigorous aeration along stream lines at right angles to the flow and with the aid of a submerged deflector, secondary aeration is produced, also a circulating spiral flow between inlet and outlet. Other means of agitation have been found to be unnecessary. The most economical power consumption is obtained by the choice of bristles, their number and spacing, and the number of revolutions in relation to the necessary minimum dip for causing sufficient circulation.

Return sludge is recirculated by a water wheel making three to five revolutions per minute, consuming but little power because of low speed and low lift. The water wheel is driven from the shaft actuating the brushes through reduction gears. The quantity of return sludge is controlled by the depth of immersion of the water wheel. The operation of the whole bio-aeration plant is dependent only upon the adjustment of a screw telescopic valve fixed on the outlet of the sludge pipe, governing the return of sludge. Accurate adjustment of returned sludge allows purification of concentrated wastes in deep tanks by reducing the strength at the inlet by dilution with large amounts of return sludge. It is of importance to determine the oxygen demand of the untreated waste in order to fix the rate of the required dilution of influent with return sludge and the percentage of sludge necessary. In small plants the addition of large quantities of watery sludge to the influent prevents the clogging of pipes and channels.

Equalizing tanks, in connection with small bio-aeration plants are of importance in the treatment of industrial wastes discharged intermittently, when acid or poisonous wastes are discharged at times, or possibly in cases where the cost of power varies during the day.

As with large plants, preliminary treatment is desirable with small

plants. Surplus activated sludge together with that from preliminary treatment may be carried away, without subsequent treatment, to digestion and drying. Where complete sludge digestion is necessary, preliminary treatment in Imhoff tanks is recommended, both preliminary and surplus activated sludge being dealt with in the digestion chamber. In separate digestion of sludge, gas utilization may be of value, heat, agitation and chemicals being used to intensify methane fermentation.

Plants of the type described have been in operation close to dwellings without causing nuisances from odors or flies. A company undertaking a housing development is at present contemplating the construction of such a plant in the central public square. The advantages of such works are an economic sewerage system in a district comparatively flat with a high subsoil water level and no loss of expensive building area.

Some Biological Notes on Sewage Disposal Processes

BY H. TAYLOR

The Surveyor, **73**, 32–33 (July 11, 1930)

ABSTRACTED BY H. W. STREETER

On first examining microscopically a normal activated sludge in good condition, the most obvious life is protozoal. One sees a confused mass of apparently inert matter and in the clear space, active stalked ciliates, such as *Vorticella* and *Carchesium*, walking animalcules, such as *Aspidisca* and *Euplotes*, and other free-swimming flagellate and ciliate protozoa. Continued observation of these protozoa, which usually abound in good sludge and are less numerous and active in poor sludge, leads naturally to the thought that they play an active part in purification.

From continued examination it is observed, however, that clarification and purification remain unaffected when protozoa are present in only small numbers. Hence it is concluded that protozoa have little bearing on the clarifying and purifying power of the sludge, though their type and numbers may indicate a certain condition of the medium.

Under a high-power microscope, the bulk of activated sludge is composed of jelly-like masses, containing numerous bacteria. This is a typical zooglea formation, caused by fusion of the gelatinous sheath surrounding bacterial cells. Apparently this growth is the only constant factor in activated sludge.

The usual form of the zooglea is an irregular, lobed mass, but at times a branching, filamentous form often closely associated with *Sphaero-*

tilus natans predominates. In a chloroformed sample of liquid from an aeration tank, a gray gelatinous mass formed at the surfaces of the sludge and liquid. On examination, this growth was shown to be a bacterial zooglea, both lobed and branching, in which were growing young filaments of *Sphaerotilus*. After a considerable time a brownish growth of an iron bacterium, *Leptothrix ochracea*, developed.

Purification Effects of Zooglea.—During a cool, rainy period, when the sewage was much diluted and conditions were favorable to aerobic growths, a profuse gray gelatinous growth was observed on the outlet sills of the primary sedimentation tanks. These masses were collected, washed free of septic matter, introduced into two bottles of tank effluent and the mixture aerated for 4 days, effluent being withdrawn and replaced by an equal volume of sewage each day. The results showed a marked purification effect by the zooglea masses (though clarification was poor) and that these masses develop rapidly in crude sewage under good aeration. In a duplicate experiment, under different conditions, clean zoogleal masses were crushed in a mortar and aerated with dilute sewage for 24 hours. The rapidly settling portion of the mass was separated, well washed with distilled water, added to fresh sewage and the mixture aerated, with daily abstraction of effluent and replacement by sewage. The result, showing marked purification and clarification, is interpreted as indicating the purification effect of zoogleal masses in accord with observations already published.

Higher Forms of Sewage Life.—In the majority of activated sludges examined, the stalked ciliates, *Vorticella*, *Carchesium* or *Opercularia*, have been present in large numbers; the walking animalcules, *Aspidisca* and *Euplotes* are frequently present; of the *Suctoria*, a species of *Podophyra* is fairly common; *Stylobryon* and *Dinobryon* are also common; the Sarcodina are represented by a few naked amoeba and at times *Arcella vulgaris* has been numerous. Rotifers and nematode worms also are seen and occasionally numerous *cyclops*. The algae are represented chiefly by diatoms and filamentous blue-green algae.

Organisms Peculiar to Final Settling Tanks.—These include many organisms found in the sludge, often fixed and filamentous, with protozoa and other animals living among them. Algae naturally predominate. The highest plant form is the common duck-weed, *Lemna*. The thin deposit of sludge on the inner sides of the settling tank below the water line is usually overgrown with algae near the surface and also contains diatoms in large numbers, blue-green and green algae and the higher bacteria, particularly the sulphur bacteria, *Beggiatoa*, which find in the presence of hydrogen sulphide and dissolved oxygen conditions favorable to free development. *Carchesium* is plentiful and amoeba are more numerous than in the activated sludge. Nematode worms and rotifers are

common. The outlet sills are usually covered with green algae and in the covered portion of the effluent channel, *carchesium* abounds. In long-standing samples of tank effluent, *Anthrophysa vegetans*, with its prominent brown stalk, has been observed.

Filamentous Growths and Bulking.—Bulking of sludge has caused serious trouble in activated sludge plants. In several cases observed, filamentous growths have been present in abnormal amounts. The organism usually has been reported as *Sphaerotilus* though many points of difference have been noted. Though unable to name the organism, the author believes that it belongs to the *Myxophyceae*. He reports that addition of lime did not overcome the bulking trouble.

Sewage Fungus.—The fungus *Leptomitus lacteus*, previously designated as the "sewage fungus," is, in the author's experience, of rare occurrence in sewage. *Sphaerotilus natans* is much more frequent and what is often termed the "sewage fungus" is the protozoan *carchesium*.

Action of Enzymes on Sewage Solids

BY NOEL S. CHAMBERLIN

New Jersey Agricultural Experiment Station, *Bulletin* 500 (March, 1930)

ABSTRACTED BY E. HURWITZ

Systematic studies were made to determine the effect of enzymes on gasification, liquefaction, swelling and dewatering of fresh sewage solids and to determine the concentrations of these enzymes during the course of digestion. The studies are divided into five parts and each part is discussed in detail under its particular heading.

Part I. A Quantitative Determination of a Few of the Enzymes Occurring during Digestion of a Properly Seeded Mixture.—The quantity of enzyme present in the sludges was determined either by measurement of the disappearance of a substrate or by measurement of a by-product formed from a substrate. The presence of *lipase* was determined by its action upon a substrate containing fat (butter-acacia or castor oil), the amount of acid liberated from the fat being titrated. *Pepsin* was determined by the method of Volhard and Löhlein which employs the ability of casein to combine with a definite amount of hydrochloric acid and to liberate this acid quantitatively as digestion of the protein proceeds. The free HCl is titrated. The presence of *trypsin* was determined in a manner similar to pepsin except that use was made of the activity of trypsin in alkaline solution. *Diastase* was determined by the Wohlgemuth method which depends on the digestion of starch to dextrin. The

disappearance of the starch is shown by the change of color from blue to red on the addition of a few drops of iodine. *Rennet* was determined by the coagulation of raw skimmed milk, the casein being converted to paracasein.

The work was divided into four distinct tests, the enzymes being tested in the following order: Test A—lipase, pepsin, trypsin; Test B—lipase (butter-acacia and castor oil method), diastase (24-hour test), pepsin, trypsin; Test C—diastase (2-hour test), rennet; Test D—pepsin, trypsin.

The results of these tests are shown in a series of curves in which the enzyme values are plotted against time in days. The daily gas production per gram of volatile matter is also plotted in a curve. Comparison of the different curves obtained for a given enzyme shows some variation among the tests and also shows that the values for a specific enzyme do not follow the gas curve for each test in like manner. Hence to obtain a better picture of the enzyme activities, the average results of the different tests have been plotted.

The quantitative determination of the few enzymes occurring during digestion of a well seeded mixture shows that: (1) Lipase has two peaks of activity—one to digest the lower fats before maximum gasification and the other to digest higher fats and oils after maximum gasification. (2) Diastase has a peak of activity coinciding with the peak of gasification. This activity causes decomposition of starches. (3) Rennet has its greatest activity at the beginning of digestion, coincident with the greatest decomposition of soluble nitrogenous matter. (4) Pepsin has one peak, coinciding with the gas peak. During this time it decomposes proteins to proteoses and peptones. (5) Trypsin has two peaks, one coinciding with the first lipase peak during which proteins are decomposed, and the other occurring two weeks after maximum gasification, during which complex proteins, proteose and peptones are decomposed.

Part II. Effect of Enzymes on Digestion When Added to Properly Seeded Mixtures.—In these experiments the possibility of decreasing the time of digestion by adding enzymes was studied. In Test A the enzymes were added without regard to the optimum conditions under which they function while in Test B the enzymes were added under conditions approaching as closely as possible their optima.

The results of Test A indicated that enzymes added to seeded mixtures did not increase the rate of decomposition as shown either by gasification or liquefaction.

The results of Test B indicated that a mixture of five enzymes (lipase, trypsin, pepsin, diastase, rennet) added to fresh solids at 70° F. and at the proper reaction did not increase the rate of digestion. Trypsin increased digestion from the standpoint of liquefaction. Lipase and diastase in the presence of supernatant liquor of fresh solids increased

digestion from the standpoint of gasification. Lipase and rennet increased digestion from the standpoint of gasification in the absence of the supernatant liquor. However the increase in gasification in either case was small, being only 12 per cent.

Part III. Effect of Enzymes on Liquefaction of Fresh Solids.—The effect of enzymes on liquefaction of fresh solids was studied by seeding with each of the five enzymes and incubating under optimum conditions for 60 hours. The degree of liquefaction was determined by measuring the amount of reduction of solids in 100 cc. fresh solids, the liquid first being removed by filtering under suction. The weight of the wet solids on the filter was obtained and the dry solids were determined by drying a portion of this at 105° C. The effect on sterilized fresh solids was also studied.

The results of the experiment show that only in the case of lipase was liquefaction appreciable, the reduction in solids amounting to 12.6 per cent. Liquefaction of sterile fresh solids was negligible.

Part IV. Effect of Enzymes on Swelling of Fresh Solids.—The effect of enzymes on the swelling of fresh solids was determined by measuring the amount of swelling in graduated cylinders. The results of the test indicated that only lipase and pepsin affected the swelling of fresh solids. Lipase hastened the swelling enormously in the early hours of the test but fell below the usual degree of swelling after a few hours. Pepsin hastened swelling to a less degree at the beginning but tended to become normal after 50 hours. The results are shown in a table and a curve in which the swelling in cubic centimeters is plotted against time.

Part V. The Effect of Enzymes on the Dewatering of Fresh Solids.—The procedure used to determine the effect of enzymes on the dewatering of sludge is similar to that used in Part III. The filtrate from a Buchner funnel containing 100 cc. of solids at the start was caught in a graduated cylinder and the volume noted at various intervals. In some tests ferric chloride was used to assist in dewatering. The results as shown by a series of tables and curves indicated that in the absence of ferric chloride enzymes had no effect on dewatering fresh sewage solids. Enzymes in the presence of ferric chloride showed some improvement over ferric chloride alone. Trypsin in the presence of ferric chloride was the only enzyme used which showed an appreciable decrease in the final moisture of the filter cake, as compared with ferric chloride alone. The moisture removed by trypsin was 13.8 per cent greater than by ferric chloride. All other enzymes used removed less than 10 per cent more moisture than ferric chloride alone.

River Pollution Problem. Recommendations of Joint Advisory Committee

Surveyor, **78**, No. 2012, p. 161 (Aug., 1930)

ABSTRACTED BY C. T. WRIGHT

In the second report of the Joint Advisory Committee on River Pollution, issued by the Ministry of Health, the Committee recommends that Section 7 of the River Pollution Prevention Act of 1876 be repealed and the general law amended. The following recommendations are proposed by the committee:

1. That the local sanitary authorities should be obligated to take and dispose of the trade effluents of their district, and that the trader should have the right to discharge such liquids to the public sewers.

2. That the local authorities should be empowered to make general regulations governing the right of the trader, imposing necessary safeguards and conditions with which he must comply. The terms of the agreement to be drawn up between the interested parties and questions in dispute should be determined by the Minister of Health.

3. That the local authority should be qualified by means of these regulations to call for preliminary treatment, for the removal of specified substances and for the regulation of the rate and volume of discharge; to impose reasonable charges for the facilities afforded, and to provide for the control of operation of existing works.

4. That the local authority should be enabled to construct or provide separate sewers or works for the reception and disposal of these wastes or by means of combined schemes to treat wastes from two or more trade premises separately from their general sewerage system; the local authority should have the power to dispose of sludge and similar matter from the trader's premises at his expense.

5. That nothing in the new code should affect existing riparian rights in the volume of water used or discharged.

6. That the Minister of Health should have the power to extend the various periods prescribed in the recommendations or to suspend the operation of the system in any area.

The Permissible Loading of Streams by Sewage

BY DR. ING. MAHR, RUHRVERBAND, ESSEN

Technisches Gemeindeblatt, **32**, No. 15 (Aug. 5, 1930)

ABSTRACTED BY J. K. HOSKINS

In a previous article in the same journal (Nos. 15 and 16, 1929) the authors developed a formula for the minimum permissible dilution of sewage in streams, taking account only of the dissolved polluting material. It was

therein suggested that the dilution should be such that the one-day oxygen demand of the dissolved matter added should not exceed the oxygen supplied by reaeration during one day, thus,

$$Q = \frac{q\,t\,S}{5a}$$

where Q = volume of river water in m.^{3} per second
q = average daily sewage contribution in m.^{3} per second
S = 20-day biochemical oxygen demand of filtered sewage in g./m.^{3}
a = reaeration per day of river water in g./m.^{2}
t = cross-sectional depth of river in meters

In this article the permissible load of undissolved organic material is discussed.

The suspended material added to streams is deposited on the stream bed in the immediate vicinity of the sewer outlet and hence is not oxidized uniformly throughout the stream length. The rate at which this sludge layer may be permitted to be built up and oxidized and yet not exceed the oxygen capacity of the overlying water is also capable of expression if certain assumptions are made. Assuming that sedimentation is complete in the receiving stream two hours after addition of the undissolved material, that the layer is of uniform thickness, that it becomes inert after 100 days and that the thickness of the active oxygen-consuming layer must not exceed 2 centimeters, the author derives the expression,

$$Q = 60\,q\,b\,t$$

for the permissible loading of insoluble organic material only and in which b = the average sludge content of sewage in cubic centimeters per liter or in liters per cubic meter.

Combining these two expressions for the case where both dissolved and suspended matter are added to the same volume of river water there is obtained

$$Q = q\,t\left(\frac{S}{5a} + 60\,b\right)$$

The effect of temperature on the ratio of reaeration and of oxidation is discussed in the light of American publications on this subject. Because of this temperature effect the load imposed on a river must be less in winter than in summer if the polluting material is to be oxidized in the same stream length; on the other hand the winter load may be greater if the river is required only to transmit the pollution without nuisance. This rule is applicable both to dissolved and suspended matter. Again, less pollution is allowable in summer because then the oxidation rate is more rapid, comparatively, than the rate of reaeration and consequently the same volume of organic matter may result in oxygen depletion with the warmer temperature. Moreover, gasification of bottom sediments at temperatures over 20° C. results in floating sludge unless the pollution load is reduced a sufficient time in advance of higher temperatures to obviate this difficulty.

Fifth Annual Report (1929) of the Missouri Water and Sewerage Conference

ABSTRACTED BY H. GLADYS SWOPE

The following papers dealing with sewage problems were presented at the Fifth Annual Meeting of the Missouri Water and Sewerage Conference held in Chillicothe, Missouri, October 21–23, 1929.

"Sewage Treatment in Missouri," by W. Scott Johnson. This paper was published in THIS JOURNAL, I, 4, 597–601 (October, 1929).

"Production and Collection of Sewage Gas," by George S. Russell. Following the experimental work conducted at Antigo, Wisconsin, in which the gas collected from the separate sludge digestion tank was used to heat the water in the coils of the digestion tank, a similar plant was constructed at Springfield, Missouri. A larger tank is required if the tank is not heated, as the sludge digests much more slowly at low temperatures. For a population of 45,000 at Springfield, Missouri, two tanks, 50 ft. in diameter and 21 ft. deep, would be necessary if unheated, or one tank 65 ft. in diameter and 20 ft. deep, equipped with gas domes and heating coils. The bids on the two designs were practically the same, consequently the latter was constructed. The use of heat in the digester has kept the sludge in excellent condition, and the pH has never been below the neutral point, generally averaging between 7.2 and 7.3. Collection and utilization of the gas eliminates odors, keeps the sludge under optimum conditions for sludge digestion, and reduces costs.

"Sewer Rental Charges," by N. T. Veatch, Jr. The operation of sewage treatment plants is very often neglected because of ignorance on the part of the public, an improperly designed plant, or overloading of the plant. Funds must usually be obtained through bonding issues, and in some states the amount that can be raised is limited by statute. To overcome this difficulty two states, Michigan and Ohio, have inaugurated sewer rental charges, which are assessed similar to water assessments. These sewer rental laws provide money enough to keep existing plants in first-class condition and allow for the construction of new works.

"Records and Tests for Sewage Treatment Plants," by H. M. Bosch. Tests should be made and records kept at sewage treatment plants in order that the efficiency of the plant may be known, as a basis for evidence in case a suit is filed against the city for damages supposedly caused by the treatment works, and in case the existing plant is to be extended or rebuilt. The temperature of the raw sewage, sludge and air should be known. The temperature in the digestion chamber influences materially the amount and kind of digestion accomplished. The efficiency of the grit chamber is best determined by determining the volatile organic matter in the grit. The Imhoff cone test is indispensable for determining removal

of settleable solids in Imhoff or separate digestion tanks. In activated sludge plants a cylinder is better than a cone for this test. The best method for determination of suspended solids is by the use of a Gooch crucible. For knowing the entire efficiency of the plant the best index is the biochemical oxygen demand. A simpler test (but not very reliable) is that of methylene blue stability. A record of the daily flow of sewage should be made. Data on sludge withdrawal should be kept, which should include date of withdrawal, amount drawn, quantity of dry sludge yielded, quality of sludge, pH, and moisture content.

"Progress Made in Sewage Treatment," by C. K. Mathews. Primary treatment includes the settling of the heavier solids, control of their decomposition and disposal of the residual sludge. Primary treatment is obtained by use of septic tanks, Imhoff tanks, or sedimentation plus separate digestion tanks. Secondary treatment is the stabilization of the settled sewage liquor and may be accomplished by sand filters, contact beds, trickling filters, or the activated sludge process, with or without mechanical agitation. All of the methods are briefly discussed. Sewage treatment at Sedalia, Missouri, is accomplished in three treatment plants. The sewage reaches each plant by gravity. The southeast plant was constructed in 1911 and serves a population of 4500. There are four septic tanks operated in parallel. The effluent is treated on contact beds, and the sludge is drawn directly into a creek. The northwest plant was built in 1916, and serves a population of 4800. This plant consists of two Imhoff tanks operated in parallel. The effluent is treated on a sprinkling filter and sludge is run onto drying beds. The southwest plant was put into operation in 1928 and treats a population of 8500. It is of the separate digestion type. The effluent is treated on a sprinkling filter which is provided with a means of circulating air through the filter material.